EXPERIMENTAL AGRICULTURE

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EXPERIMENTAL AGRICULTURE

BEING

THE RESULTS OF PAST, AND SUGGESTIONS FOR FUTURE EXPERIMENTS

IN

SCIENTIFIC AND PRACTICAL AGRICULTURE

BY

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JAMES F. W. JOHNSTON

F.R.SS.L. & E., &c. &c.

"No man ought to be discouraged if the experiments he puts in practice answer not his expectations; for what succeeds pleases more, but what succeeds not, many times informs no less."—Bacon.

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INTRODUCTION.

When, about eight years ago, my attention was first closely directed to scientific agriculture, I was surprised to find in agricultural works so few rigorous experimental data on which to base safe opinions of my own, or by which to test the published opinions of others. With the view of gradually collecting a body of such data, therefore, I published several series of *Suggestions for experiments in practical agriculture*, both in a separate form and as an Appendix to the first edition of my published *Lectures on Agricultural Chemistry and Geology*. These suggestions attracted considerable attention on the part both of individuals and of societies. Many skilful practical men, among whom I ought to distinguish Mr Fleming, of Barochan, in Renfrewshire, undertook field experiments at their own cost and on their own land. The Royal Agricultural Society of England, also, and the Highland and Agricultural Society of Scotland, offered premiums for such experiments, and their example was followed by several local societies, such as that of Turiff in Aberdeenshire, of Strathmore in Forfarshire, and of Guildford in

Surrey. The consequence of this has been the publication from time to time, and especially in the *Transactions of the Highland and Agricultural Society of Scotland*, of the results of numerous experiments with saline and other substances applied to different crops, in soils of nearly all varieties, and upon many geological formations.

These experiments, however, are often contradictory in their results, often incorrectly or carelessly made, and occasionally exhibit, when criticised, evidences of total untrustworthiness. But they have never been criticised as a whole—the good separated from the bad, and the value of the experimental data they afford us candidly weighed.

This I propose to do in the following pages. And though my examination of what has hitherto been done in the way of field experiment, has led me to the conviction, that scarcely any of the results we have as yet obtained are to be relied upon as secure grounds for scientific opinions ; yet they may be considered to have cleared the path to surer results, by pointing out sources of error previously unknown, and thus indicating the precautions which must be adopted in future trials.

In my previously published works, I have embodied, so far as I could, all that was known, with any degree of certainty, in regard to the applications, especially of chemical science, to practical agriculture. But there is a vast deal yet unknown altogether—scarcely half understood—or in regard to which we possess only the assertions or opinions of individual men. To these obscure parts of the subject, in so far as they appear capable of being im-

mediately elucidated by experiment, it is my intention to advert in the present work, by way of suggesting trials in the field or feeding-house, out of which we may hope to see light spring up.

To individuals anxious to enter upon such practical investigations—and there are many such—the suggestions I have ventured to offer will point out what they may respectively do for the advancement of scientific agriculture. To societies, I believe, they will be no less valuable in indicating what they may, by premiums and other forms of encouragement, stimulate their members beneficially to undertake.

It is only by means of conjoined experiments in the field, the feeding-house, and the laboratory—all made with equal care, conscientiousness, and precision—that scientific agriculture can hereafter be with certainty advanced. If we have been long in getting upon the right road, we ought to advance the more heartily now we have found it.

DURHAM, *August* 1849.

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PART I.

OF THE KNOWLEDGE REQUIRED BY A SUGGESTER AND MAKER OF EXPERIMENTS, AND OF THE WAY IN WHICH EXPERIMENTS OUGHT TO BE MADE AND CRITICISED.

EXPERIMENTAL AGRICULTURE.

CHAPTER I.

Knowledge necessary in a suggester and maker of experiments. Purposes for which experiments in science are made. Object of the suggestions contained in the present work. Substances of which plants consist. Functions of the organic and mineral constituents, and of the several parts of plants. Habits and analogies of different species of plants, and of their varieties. Of what the soil consists. Influence of its geological origin. Value of an acquaintance with the local geology, and with the local drift, prevailing winds, and physical geography. Composition of local streams and rocks.

§ 1.—*Purposes for which experiments are made. Object of the suggestions contained in the present work.*

THE ultimate aims of applied science, in its relations to agriculture, will be the more fully and speedily attained in proportion as it succeeds in converting the practical farmer into a skilful, reasoning, and cautious experimenter, and every agricultural holding into a progressing and profit-giving experimental farm.

Experiments in chemical science are made with the view either of illustrating what is known, of testing what is asserted, or of discovering what is unknown.

In the *first* case they are intended either—

1°. To exhibit the known properties and mutual relations of bodies, and their influence upon animal and vegetable life; or,

2°. To demonstrate received theoretical views in reference to these known properties and relations.

These are merely illustrative experiments, such as the chemical lecturer makes before the audience he is instructing.

In the *second* case, they are intended to try alleged facts; to test hypotheses; to determine whether observations said to have been made have been made correctly; whether conjectures thrown out have any foundation in truth; whether theories propounded are deserving of a place in our books, or ought to be banished altogether from their pages. These researches of the experimental critic are as valuable and important as any which can be made. To them we must be indebted for clearing away much rubbish which at present finds a place in our works upon scientific and practical agriculture.

In the *third* case, they are intended to discover new properties, relations, and useful applications of bodies; to determine more accurately and more fully the circumstances by which these relations and applications are modified; and thus to help us forward to the establishment of new or more general theoretical principles, and of new practical deductions.

To these last the term *research* most strictly applies, though, with a view to both the second and the third of the objects specified above, experiments in the field and the feeding-house are fitted to render much service to the arts of rural life.

In suggesting the experiments proposed in the following pages, it has been my intention, among other things,—

First, To bring into view the numerous weak, or doubtful, or altogether dark points in our present knowledge of agricultural theory; and,

Second, Critically to consider the bases on which our opinions in reference to many practical points really rest. Weak points in theory, and uncertainties in practice, ought to be fairly stated and considered. Instead of being covered over and hidden by confident assertion, they ought to be made the subject of experiment in the field or in the feeding-house, and of analytical research in the laboratory. It is to field and feeding experiments that I intend principally to confine the attention of my readers in what is to follow, though I shall not fail to indicate from time to time those experimental researches in the laboratory which appear most urgently to be required.

Such a procedure will benefit agriculture, not merely by suggesting to individual cultivators what may prove interesting and instructive additions to the ordinary labours of the farm, but also by putting into the hands of agricultural societies—now so often at a loss for subjects of intellectual interest to which the attention of their members may be drawn, or for which premiums may be offered—an almost boundless field of inquiries, upon which their labours may year after year be beneficially expended; inquiries, each of which will tend to awaken thought and excite discussion, while they are of a kind, also, upon which the least cunning in agriculture will not venture to cast ridicule.

Some years ago, the Highland and Agricultural Society of Scotland began to offer premiums for experiments in the field, founded on the suggestions contained in the appendix to the first edition of my published *Lectures*.* The Royal Agricultural Society of England also took up the same subject, though less warmly than the Highland Society, and still more limited exertions in the same walk have been made by many provincial societies. These premiums caused many persons to undertake such experimental inquiries, many competitors appeared for the prizes which were offered, and a large body of valuable results has from time to time been published, especially in the *Transactions* of the Scottish Society.

But, with the award of the premiums and the publication of the results, the labours of the Societies have ended. The experiments and their results have never been criticised, compared, or digested,—their merits or defects carefully and candidly pointed out,—the purposes for which they were made, weighed against the information they yielded,—the rubbish they presented, separated from the useful matter they contained,—and the steps distinctly pointed out which ought next to be taken, in order to secure a further advance.

These things it is my wish to do to some extent in the present work. The suggestion of such a union between theoretical science and field experiment, with a view to the more secure and rapid progress of agriculture, originated very much with myself; and I feel bound, in so far as my knowledge and leisure

* *Lectures on Agricultural Chemistry and Geology.* Blackwood : 1844.

permit, to show how much we have as yet attained, how our methods of experimental procedure may be improved and made more reliable, and what new inquiries may be entered upon, in the hope of solving the numerous agricultural problems which lie still unexplained before us.

The progress of scientific agriculture cannot fail to be greatly promoted by an extension of the habit of cautious experimenting, and the multiplication of results in which confidence can be placed. But many persons, capable of benefiting the art of culture in this way, are unaware of the points which chiefly require to be investigated, and in what way the investigation is to be commenced; while others are now groping in the dark, uncertain, and therefore unsuccessful, in their experiments. Many also, who have hitherto felt no interest in such pursuits, require only to have their objects clearly set before them to become warmly and zealously devoted to them. These have served as additional inducements to me in preparing the following pages.

§ 2.—*Knowledge which ought to be possessed by the suggester and performer of agricultural experiments.*

The suggester of experiments in scientific and practical agriculture ought to be guided by a knowledge, in so far as it is understood,—

1°. Of the various substances of which plants consist, or which they require to promote their growth, and of the most important chemical properties, mutual relations, and chemical combinations of these substances.

2°. Of the functions performed by these substances in the soil and in the plant at different seasons, and at different periods of the plant's growth.

3°. Of the forms of chemical combination in which these substances usually exist in the soil, enter into the roots, circulate in the sap, and fix themselves in the solid part of the plant.

4°. Of the general chemical composition of soils, of their local origin and natural differences, and of the local sources of supply (if any) of those substances which plants especially require, in the district where the experiments are to be made.

5°. Of the nature of natural and artificial manures, of the general principles and practices of husbandry, of the special husbandry of the district—of its physical character, its geological structure, and of its general climatic relations.

6°. Of the habits of the species of plants on which the experiments are to be tried, and of the more common varieties of these species—their tendency to become prolific, to degenerate, to be attacked by insects, by parasites, or by disease—their relations to certain physical characters of the soils in which they prefer to grow, &c.

7°. Of the general habits, principal varieties, constitutional tendencies, and especially of the structure of the digestive organs of the animals on which experiments in feeding are to be made.

8°. Of the exact state of our theoretical knowledge upon points akin to those on which the proposed experiments are intended to throw light, of the experiments (if any) which have been previously made and published in reference to the same subject, of the way in which they were made, and the *quality* of the results they have yielded.

9°. Of a clear and definite purpose or end, practical or theoretical, for which the experiments are to be recommended and undertaken.

In the *maker* of the experiments, all this knowledge is not required. He cannot possess too much of it—for none of it would be superfluous or without its use—but scrupulous fidelity and accuracy in all his proceedings, a careful observation and detail of appearances, and a conscientious record of results, are the most essential qualifications on his part. It is as in a chemical laboratory, where a head and hands are both requisite in the chief—while, in the subordinates, skilful, ready, and willing hands are most especially required.

I shall briefly advert to the several heads of knowledge with which the suggester of experiments ought to be conversant.

§ 3.—*Substances of which the plant consists.*

The plant consists essentially of two parts—an organic and a mineral part. The former burns away when a plant is put

into the fire, the latter remains behind in the form of ash. Both these portions are dependent upon, and in whole or in part supported by, the food which the plant derives from the soil. The mineral part is drawn from the soil alone, by the roots; while, of the organic part, one portion comes from the soil through the roots, and another portion from the air through the leaves.

The organic part of plants consists of four elementary or simple bodies: carbon, hydrogen, oxygen, and nitrogen. In all the parts of plants these four are associated also with minute quantities of sulphur and phosphorus, which are more or less completely dissipated into the air when the plant is burned.

Of the four substances above-mentioned, the nitrogen appears to be drawn by plants almost exclusively from the soil—a fact of much importance to the practical man, in whose soil, of course, it must be present, if plants are to grow well upon it. The hydrogen and oxygen are drawn partly from the soil and partly from the air—chiefly in the form of water, which consists of these two elementary substances. The carbon is derived only in small proportion from the soil, being for the most part sucked in from the air by the leaves, in the form of carbonic acid gas. Sulphur and phosphorus come from the soil only.

The mineral part of the plant, which forms from half a per cent to fifteen or even twenty per cent of the whole weight of the dried plant, consists of from eight to twelve different substances. These are potash, soda, lime, magnesia, oxide of iron, oxide of manganese, alumina, chlorine, sulphuric acid, phosphoric acid, silica, and probably fluorine. Of these substances, alumina is very rarely present in appreciable quantity, at least in our usually cultivated plants, and may therefore be neglected. Silica exists chiefly in the stems of the grasses, in the stalks of corn, in those of the cane and bamboo, in the husk and chaff of grain, &c., and in small proportion only in the softer parts and juices of plants. Potash, soda, chlorine, and sulphuric acid, are for the most part found in the sap; lime, magnesia, and oxide of iron, in the solid parts of plants. Phosphoric acid is necessary to, and is found in every part of, a plant; but it collects in

larger proportion in the grain or seeds as the season of ripening approaches. Fluorine has as yet been little sought for. It is present in very minute quantity, and is probably associated with the phosphoric acid.

The relative proportions in which these several mineral substances enter into the composition of the several parts of plants, and the variations which these proportions undergo, in different circumstances, are very interesting branches of study, upon which it would be out of place here to touch. They are treated at length in my other published works. I only here remark of the oxide of iron, that, though often present in small quantity only, it is never absent from a plant, and that the oxide of manganese is frequently met with in so minute a proportion as to be incapable of estimation, and is therefore, like fluorine, often omitted in the detail of the substances found when the ash of the plant is subjected to analysis. Why these substances are assumed to be always present in plants, even when they are not to be sensibly detected, and especially, why iron in notable proportion must be contained in all vegetable food, will appear in a subsequent section.

§ 4.—*Functions performed in plants by their organic and inorganic or mineral constituents.*

The substances mentioned in the preceding section as occurring more or less abundantly in all plants, perform in them at different times, and in different parts of the plant, three general functions.

1°. They all form, more or less constantly and abundantly, a portion of the fixed and solid matter of the plant, taken as a whole. They may not all be found in any one part of the plant, when separated carefully from the rest; but in the solid parts of the plant, taken as a whole, they are all and always to be met with. When thus deposited, they become for the most part dormant as it were, and for the time cease to perform an active chemical function in the general growth, though as vessels or cells they may still perform a mechanical function.

2°. They undergo various chemical changes in the interior, chiefly while circulating or contained in the sap, by which

changes they are prepared and fitted for entering, when and where it is necessary, into the composition of the solid or fixed parts of the plant. Thus the starch of the seed is changed into the soluble dextrine and sugar of the sap of the young plant, and these again into the insoluble cellular fibre of the stem or wood, as the plant grows, and finally into the insoluble starch of the grain, as its seed fills and ripens.

3°. They each exercise a chemical action, more or less distinct, decided, and intelligible, upon the other elementary bodies and the compounds of them which they meet with in the sap of the plant. In regard to some substances, such as the potash, the soda, the sulphuric and the phosphoric acids, this last function appears to be especially important. These substances influence all the chemical changes which go on in the interior of the plant, and which modify or cause its growth. The same is true of the nitrogen which the plant contains. This elementary body, in the form of albumen or some other of the numerous protein compounds which occur in the sap, presides over, or takes part in, almost every important transformation which the organic matter of the living vegetable undergoes. Thus it is always abundantly present where the starch of the seed or of the tuber (as in the grain of wheat or in the potato) is dissolved and sent up to feed the young shoot; and again when the soluble substances of the sap are converted into the starch of the grain, of the tuber, or of the body or pith of the tree, one or other of the protein combinations is always found to be present on the spot where the chemical change or transformation is going on.

Besides their general functions, therefore, the several substances found in plants exercise also special functions in reference to vegetable life and growth. Thus *nitrogen* is most abundant in the sap of young plants, takes part in most of the changes of organic compounds which go on in the sap, and fixes itself as the plant approaches maturity in greatest abundance in the seeds and in the green leaves.

Potash and soda circulate in the sap, influence chemical changes very much, and reside or fix themselves most abundantly in green and fleshy leaves, and in bulbous roots.

Sulphuric acid is very influential in all chemical changes, is

found in most cases in those parts of the plant in which potash and soda abound, and deposits a portion of its sulphur wherever the compounds of nitrogen form a notable part of the substance of the plant.

Phosphoric acid exercises also much influence over the chemical changes of the sap, and finally fixes itself in greatest abundance in the seeds and other reproductive parts of the plant.

Lime is very important to healthy vegetable growth, as practical experience has long testified. Among other duties, it appears to accompany the phosphoric acid in the sap of plants, and to deposit itself in combination with organic acids (oxalic, &c.) in the leaves and bark, and with phosphoric acid in some seeds and roots.

Magnesia appears also to attach itself very much to phosphoric acid in the sap, and fixes itself, in combination with this acid, principally in the seed.

Chlorine, the chemical function of this substance in the sap, is less understood even than that of the other substances above mentioned. It exists chiefly in combination with soda, and is much more abundantly present in some plants, and in some parts of plants, than in others. Though, as I have said, its immediate chemical function in the plant is not understood, we shall see in a subsequent section that it forms a most important constituent of the plant, in so far as the after uses of vegetables in the feeding of animals are concerned.

Silica exists in the sap in a soluble form, and deposits itself chiefly in the exterior portions of the stems and leaves of plants. It is supposed there to serve as a defence to the plant against external injury, and to give strength to the stem, in the case of the grasses and corn-yielding plants; but what chemical functions it performs, if any, in directly promoting vegetable growth, we can scarcely as yet venture even to guess.

§ 5.—*Functions of the several parts of plants.*

The functions of the several parts of plants are of two kinds—external and internal, or mechanical and chemical, as they may also be called. These two kinds of functions are by no means equally well understood.

1°. *The roots.*—The roots mechanically absorb or drink in, from the soil, the various substances which the plant can derive only from the soil. In doing so, they refuse to take up all substances, even when they are readily soluble in water, indiscriminately or in equal proportions. They appear to exercise a kind of selecting power, inasmuch as, while some substances are taken in readily and abundantly, others enter with difficulty, or in small comparative quantity. In this respect, the roots of different plants also exhibit diversities. It is probable that the structure and substance of the pores or cells, through which the food passes into the extremities of the roots, vary with the genus or species of plant, and that such variations have an influence upon the proportions in which different substances are absorbed by them.

Upon the food, after it has entered, the roots exercise a chemical action, at least such an action is exercised upon it as it ascends towards the stem. Scarcely has a substance been absorbed than it undergoes a chemical change more or less sensible. Coloured substances, such as madder, are seen to become colourless; but our knowledge regarding these chemical changes is general only, and we can as yet do little more than guess at their nature, from the substances which we afterwards find in the sap.

2°. *The stem* transmits the fluids and food absorbed by the roots upwards to the leaves. This is its mechanical action. As it ascends, the sap changes. The substances it holds in solution are decomposed or compounded, and thus converted into new chemical combinations. It is in reference to these changes that the stem appears to perform a chemical function. But here also our knowledge is limited. We know that certain solid substances, such as wood and starch, are deposited and fixed; certain others, such as sugar, formed in the sap; and certain others, again, given off in the state of gas or vapour from the leaves;—but we cannot tell at what point these changes take place, by what immediate agencies they are effected, nor through what successive steps of change the elementary bodies proceed in their progress towards the results which we discover to have been at last produced.

3°. *The leaves* absorb carbonic acid from the air while the sun is above the horizon, and give off oxygen in nearly equal bulk. In the dark, on the other hand, they give off carbonic acid and absorb oxygen. They also alternately absorb or exhale watery vapour, according as the atmosphere in which they live is saturated with moisture or otherwise. The quantity which escapes from them during the hot weather of summer is thus often very great. Nitrogen is also given off by the leaves of plants in variable, but sometimes, it is said by Draper, in very considerable quantity, and the petals or leaves of their flowers habitually disengage this gas to a sensible extent. Such are the mechanical functions of the leaf.

Their direct chemical functions are obscure. Carbonic acid contains its own volume of oxygen; and as the leaves give off nearly as large a bulk of oxygen as they take in of carbonic acid, it has been supposed that the leaves actually decompose the carbonic acid directly—giving off its oxygen into the air, and working up its carbon into the starch, sugar, gum, cellulose, &c., found in the sap and in the solid substance of the plant. The changes, however, are deeper seated and more complicated than this opinion implies, and for the present we must be content to confess that we do not, as yet, half understand them.

4°. *The bark.*—The sap descends through the inner bark, and during its passage those chemical changes take place which give rise, in trees, to the deposits of young wood within the inner bark. The air, which penetrates through the outer bark, probably has an influence upon these changes.

5°. *The pith.*—The pith is said to nourish the young buds till they are able to procure nourishment for themselves, after which "it is of no further importance, and dies."—(Lindley.) For this purpose it is often filled with starch. Through the medullary rays, which, like the pith, consist of vessels or rows of cells, laid horizontally, it communicates with the bark and the external air. But whether it actually admits and absorbs air, or itself, by means of these vessels, gives off gaseous matter, is, I believe, unknown.

§ 6.—*Habits and analogies of the species of plants on which experiments are to be made, and of their several varieties.*

But a knowledge of the special habits and analogies of particular species of plants, and of their several varieties—the soils on which they prefer to grow—the diseases to which they are subject—the enemies, animal and vegetable, by which they are liable to be attacked,—these things are not less important to the suggester of experiments than a knowledge of their general physiological and chemical functions.

Chemistry, from the mouths of some of its more hasty or more ardent cultivators, has promised to make any plant grow luxuriantly, and at will, upon any soil, provided only that it be suited to the prevailing climate. But such promises are mere idle boasting, and argue much ignorance on the part of those who venture to make them. Even chemistry, with all her power, must bend to the constitution and natural habits of a plant. Thus—

1°. *The oat* and the red clover love a firm and stiff soil—a natural habit, which chemistry cannot hope to change. On some soils the Tartary oat yields heavy crops, while, on the same soil, the more valuable potato oat refuses a remunerative return. Where other varieties of oats grow sound, the Hopeton oat is subject to a disease called sedge or tulip root, which is gradually driving it out of cultivation. I do not know whether these qualities of the potato and Hopeton oats be within the dominion of mechanical or of chemical causes.

2°. *Wheat.*—Winter wheat fails in many places where spring wheat is found to do well. Such a result has been observed in the island of Islay, where so many improvements have in late years been made by Mr Campbell of Islay. Is chemistry or climate, or the special constitution of the variety of wheat, or the mechanical condition of the soil, to blame for this?—and which of these causes has most to do with the capability of this or that field to grow white or red wheat, or with the greater productiveness of this than that variety of seed on similar soils?*

* For a statement or classification of the differences that occur among varieties of wheat, see Col. le Couteur's book on wheat, p. 79.

3°. *Barley* affects a lighter soil, but the quality of the grain varies with the natural dryness, the drainage, or the quality of the land; and the maltster, the feeder, or the pot-barley maker, buy it accordingly. Yet, in regard to the physical condition of the soil, different varieties have different tendencies. The chevalier barley grows on clays on which the Annat—one of our best varieties—does not succeed; and this is probably one reason why the chevalier barley has spread so widely, and yields good crops even on the Huntingdon clays. Some varieties show a great indifference as to the physical nature or condition of the soil, while others are most choice in their selection of a suitable soil. Thus the Annat variety, already mentioned, not only dislikes a clay, but a gravelly soil also, and thrives best on a dark-coloured loam.

4°. *Rice* grows usually on low alluvial flooded tracts of land, and abundance of water at the earlier stages of its existence are in most cases a necessary of life to this plant. But there are varieties of hill rice which grow healthily, and ripen on dry land. This difference, though a little more striking, is, in reality, not more remarkable or deserving of attention than the constitutional differences above mentioned in regard to barley.

5°. *The Turnip.*—The numerous varieties of turnip so generally known in this country, differ little less in habit, and tendency, and choice of soil, and power of resisting the effects of climate, than varieties of grain do. It is essentially favoured by a cold and humid climate. Hence it is a less profitable culture in our southern counties, and yields less abundant crops along our eastern borders. The yellow and the white varieties differ greatly in nutritive value and in climatic habits. Of white turnips, again, varieties differ. Thus the *white stone* comes quicker to maturity than the *white globe*; so that what is fitted to nourish and bring forward the one will not promote the growth of the other in an equal degree, or cause it in the same month of the year to yield an equal crop. In different districts, also, and under different treatment, the same variety is differently nutritive—a circumstance of much importance in all experiments on feeding.

The turnip is also liable to special attacks from insects, and

to special diseases—such as that called fingers-and-toes—accidents which are more or less completely beyond the calculations of pure or theoretical chemistry.

6°. As the cultivated carrot is the offspring of the wild carrot, (*daucus carota*,) so the white beet (*beta vulgaris campestris alba*) and the mangold-wurtzel (*beta vulgaris campestris*) are allied to the sea-side beet, (*beta maritima*,) which, like them, has a fleshy root, and is good for food. This analogy indicates the probable wants of the beet tribe, the probable utility of saline applications to the plant while growing, and the especial expediency of making experiments upon it with that common salt for which the *Beta maritima* frequents the sea-shore.

The farmers of the Guildford Club, (Surrey,) in a recent discussion on the growth of beet, came to the unanimous resolution that, in their soils, experience had shown common salt to be a valuable promoter of the growth of this root, and that it was worthy of being generally recommended.

The analogy above stated throws light on this result of practical experience, and points out to the improving experimenter the special value to him of a familiarity with such analogies: they not only modify and restrain the conclusions to which pure chemistry might erroneously lead him, but they indicate new paths of inquiry on which his chemical knowledge may exercise itself to the manifest advantage of scientific agriculture.

7°. *The pea* exhibits, among its several varieties, similar liabilities to be attacked by insects as the turnip does, and which, as in the case of the turnip, do not admit of easy or satisfactory explanation.

I lately saw on the home farm of Lord St John, at Melshburne, in Huntingdon, a field of winter peas, sown in November 1848, which had been all treated and manured alike, but on one half of which the seed sown was the early maple—a common field pea; on the other half the Ringwood marrow dwarf—a white pea. The latter was attacked at Christmas by the slugs, and in great part devoured so as to require filling up with fresh seed, while the former—the gray pea—was untouched by them. There may have been some other reason besides the difference of variety for this limited attack of the slug; but it is

obvious that circumstances or liabilities of this kind may materially modify the effect of chemical applications made to our crops, and may be the often unsuspected cause of important discordancies in our results.

I might give many other illustrations of the general habits and analogies of our commonly cultivated crops, and quote many special physiological facts, such as that dry weather makes roots like mangold-wurtzel run prematurely to seed, and that the seed so prematurely formed produces plants which, under any circumstances of weather, exhibit a similar tendency, (Stephens;) that, to succeed equally, some seeds, like that of the parsnip, must be sown new or fresh, (Le Couteur,) while others will germinate readily and healthily though kept for years, and so on; but the examples already given are sufficient to show that much other knowledge besides what is purely chemical is necessary to the suggester of agricultural experiments even of a chemical nature. His skill in regard to the circumstances in which they are likely to succeed, and therefore ought to be tried, and, above all, his ability to account for failures and discordant results, will in a great measure depend upon the possession of this practical physiological knowledge.

8°. So in experiments upon trees, no less than upon field crops, practical knowledge of a similar kind is most necessary. That the clays of the gault and weald favour the oak; that the elm flourishes only on the soils of the intermediate more sandy strata; that our cider counties rest chiefly on the old red marls, those of France on the chalks of Normandy, and the tertiary or more recent drifts which overlie them; that, in Bermuda, the coffee-tree grows luxuriantly on the recent hard calcareous rock of that island: such facts as these, with which the practical man is usually most familiar, are all of much use to the experimental adviser, and are rich in suggestions as to the kind of experiments which are likely to succeed upon each species, as to the method of making them, and as to the kind of soils on which good results are to be expected.

§ 7.—*Of what the soil consists.*

What has been said of the composition of the plant applies, with some modification, to the soil.

1°. Like the plant, it consists of an organic and a mineral part, of which the former burns away when the soil is heated to redness in the open air. They differ in this—that while in the plant the combustible part forms by far the largest proportion of the whole, the contrary is the case in the soil. The plant contains from 80 to 99 per cent of organic matter, the soil from 3 to 10 per cent only. In peaty soils, alone, it sometimes amounts to 60 or 80 per cent.

The organic part of the soil is derived, for the most part, from the remains of vegetables and animals which have been naturally or artificially buried in it. It consists, like that of the soil, of carbon, hydrogen, oxygen, and nitrogen—the proportion of the last of these, however, being usually smaller than is contained in the organic part of living vegetables.

The mineral part of the soil contains all those mineral or inorganic substances which are found in plants, besides a variable proportion of many others, which are not necessary to vegetable growth. Here again, however, there is a great difference between the plant and the soil. Those mineral substances which are most abundant in the soil are usually least so in the plant; while of those which are essential to a luxuriant vegetation sometimes mere traces only can be detected in the soil. Yet there is a purpose in this. Were they too abundant in the soil, the plant would be liable to absorb them in too large proportion, and thus to become unhealthy. This scarcity of soluble mineral matter, however, is one of the reasons why manuring with mineral substances has so often been found to produce good effects.

Silica and alumina are most abundant in the soil. The former, when in the state of sand, imparts openness, and what is called lightness, to the soil; the latter makes it stiff, tenacious, and heavy—qualities which the practical man knows to be indispensable to the successful culture of some of his most valuable crops.

Potash, soda, lime, magnesia, and the sulphuric and phosphoric acids, are usually present in the soil to the extent of a small percentage only. The oxide of iron is not unfrequently found in too large quantity. It has a tendency to collect in the under soil, and thus to prove injurious to the roots of plants.

§ 8.—*Differences of soils arising from their geological origin. Value of local geology and physical geography.*

But the relative proportions in which all the mineral constituents are found in a soil depend very much on the nature of the rocks from which the soils have been formed, or upon the physical and meteorological conditions of the district in which it lies.

1°. In a limestone or chalk country, the soil may be abundant in lime. From 20 to 30 per cent of carbonate of lime is not a rare proportion in such circumstances. In the neighbourhood of magnesian limestones, (dolomites,) magnesia is usually plentiful in the soil; in red sandstone districts, and especially in the valleys, common salt and gypsum; and, among the green sand rocks, phosphoric acid is sometimes found in comparatively large proportion; while in the lias, oolite, and coal countries, alumina and stiff clays extensively prevail.

2°. An acquaintance with the local *drift* is of especial importance in reference to the character and composition of the soil, and of the waters which flow from, or which lodge in it. A geological map tells us, through the eye, the general nature of the rocks which lie immediately beneath the surface in a given district. But, in very many cases, the actual surface is formed, not from the underlying rocks themselves, but from the debris of other rocks, perhaps at no great distance—which debris has been drifted from its place of origin, and spread over the surface of the adjoining country in the direction of the current which carried it, and has thus become the material out of which the existing soil and subsoil have been formed. Thus chalk and other drift overspreads a large part of Norfolk, forming the marls and chalky clays by means of which the cultivated surface has in that country been so much improved. The clays of Huntingdon (Oxford clay) are in many places covered with the drift of the chalk, the green sand, the lias clay, and the oolite sandstones, especially in the direction of the prevailing valleys. And here, while the soils in the bottoms are gravelly, and on the slopes freer and more easily worked and drained, they are richer also in lime; and the accidental accumulations of chalk form in places deposits

of rich marl, which may be usefully employed in subduing the stiffer clays.

In many other parts of this and of nearly all other countries, drifted materials cover the true living rocks of a district, and modify, if they do not actually form, the entire cultivated soil, as well as the subsoil which lies below it. Not only, therefore, must the local geology, properly so called, of any locality in which experiments are to be made, or when made to be interpreted, be an element in the knowledge necessary to the suggester, or to the careful weigher and criticiser of experiments, but an acquaintance with the nature of the local drift must be regarded as especially desirable.

3°. Nor are the physical geography and prevailing winds of much less importance. The rains bring down from the high grounds, either in suspension or in solution, substances which enrich the bottoms and valleys at the expense of the hills and slopes. The sea-wind, again, drives inland the salt spray which it lifts from the tops of the curling waves, and sprinkles the sea-rain over the surface, with all it holds in solution. The presence of hills arrests it, and shelters the inland slopes and valleys from the genial showers; and thus a difference, depending upon physical structure alone, is established between the soils on the opposite sides of the sheltering hills.

A coast is girt with accumulations of broken shells. Where the land is flat, as in some of our western isles, the wind sweeps the light fragments far inland, and makes the herbage as sweet as on our limestone hills, and the soil as rich in lime. But, where the land rises suddenly from the shore, the shell drift is arrested, and the soil retains the composition due to its geological origin, its natural moisture or dryness, and its nearness to the sea.

Thus physical geography and prevailing winds become important considerations to the experimental agriculturist.

§ 9.—*The composition of local streams and springs, and of local rocks.*

The soil of every field or district is watered by streams or springs of a local character, which flow over or percolate certain

local rocks. The waters of such streams, springs, and runlets are never pure. They are always impregnated with saline or mineral matter to some extent; and the nature as well as the quantity of this mineral matter depends upon the chemical composition of the rocks which the water has traversed or run over.

Waters issuing from limestone regions are loaded with carbonate of lime. When they come from red sandstone districts, or from the deep Oxford clay, common salt and gypsum often abound. Springs arising among the coal measures are sometimes rich in carbonate of soda; from dolomitic rocks and from mica slates, in salts of magnesia; and, from granites and decaying felspars, in salts of potash and soda.*

Such waters passing through, or over, or under the surface of a soil, cannot fail to affect its productiveness in a sensible degree. What the soil is deficient in, they may supply. What we add as a trial manure, they may already bring in the required proportion to the growing plant; and thus the results of actual experiment may be in opposition to the apparent natural wants of the soil, as indicated by analysis, or to results obtained with the same substance in other localities placed, to all appearance, in precisely similar circumstances. Local and limited springs may produce local and circumscribed effects. In ignorance of the existence and composition of such springs, it would be impossible to calculate upon their presence, or to make an allowance for their effects upon the crops.

* The surface water of ponds in the county of Huntingdon contains as much as 40 grains of mineral matter to the imperial gallon. In wells in the same county sunk into the Oxford clay, it amounts (at Melshburne, Lord St John's) to upwards of 70 grains in the gallon. It consists chiefly of carbonate and sulphate of lime. The water of the Thames contains about 14, and that with which Edinburgh is supplied about 10 grains in the gallon.

CHAPTER II.

Knowledge necessary to the suggester and maker of experiments, *continued.* States of chemical combination in which substances exist in the soil and enter into plants. General composition of manures, natural and artificial. General principles of husbandry. Knowledge of local practice, and of local climate. Composition, functions, and nourishment of the animal body. Structure of the digestive organs of different animals. General relations between the soil, the plant, and the animal. How analyses are corrected, and our knowledge increased, by the perception of such relations.

§ 1.—*States of chemical combination in which substances exist in the soil and enter into plants.*

It is not enough that the substances on which plants live, exist in the soil naturally or are added to it by art; they must also be present in a state in which the roots can take them up and convey them into the body of the plant.

The first condition necessary to this ready admission into the roots, is solubility in water. It is believed that—with the exception of gases, some of which may be absorbed and enter the roots, as they do the leaves, directly—all bodies must be in a state of solution in water before they can enter into the pores of the roots. Substances, therefore, which are not more or less capable of being taken up by water, are not useful in the soil till they have undergone some chemical change, by which a degree of solubility is imparted to them.

Two circumstances in connexion with this point, however, are deserving of being borne in mind—

1°. That the quantity of water which enters the roots and ascends to the leaves of a growing plant, is so great, that a very small degree of solubility is sufficient to allow of a large quantity of a substance being admitted to a plant in a single day.

2°. That even when a soil, upon chemical examination, yields

nothing to water or even to concentrated muriatic acid, the roots of plants have been found by experiment to be capable of extracting from it lime, soda, magnesia, and other substances which are necessary to their growth. This is believed to be owing to the decomposing action of water and carbonic acid in the soil, by which its rocky particles are decomposed and resolved into their constituent parts, and thus made to yield them in a soluble state to the roots.

It is necessary, however, in all field experiments, to make use of such substances only as are more or less directly soluble in water. And when mixtures of substances are employed, they ought to be in such a state of chemical combination, as not to act upon and render one another insoluble. Where these two rules are neglected, the immediate action of the single substance, or of the mixture employed, is not to be depended upon, and may not become sensible within a given time. It is scarcely possible to judge of the effect of an application which is not in a condition to act immediately, and to expend its action within a known period; to compare it with the action of other substances; or to say how far it is a profitable one, and ought to be repeated or discontinued. Patents have been taken out in this country for artificial manures, the peculiarity of which was, that such of their constituents as were readily soluble in water, should by art be rendered very sparingly soluble, and thus be liberated slowly in the soil, and slowly worked up by the plant. But the principle was a bad one, and hence the want of success which has attended both the manufacture and the numerous trials from time to time made with the manure.

The suggester of experiments, therefore, must know what compounds of each of the substances which are present in the soil and in the plant are soluble; to what extent they are soluble; and in what way they mutually affect the solubility of each other when mixed together in the soil or in an artificial manure. Thus he will know how to feed his plants; when, and with what, they have been fed; and how to judge of an experimental trial—how far it has succeeded, or what may be the cause of its failure.

§ 2.—*The general composition of manures, natural and artificial.*

This is another branch of knowledge without which no useful or comparative experiments can be made.

Manures are generally classed under the three heads, of vegetable, animal, and mineral. Those which are of vegetable origin being formed of decaying vegetable matter, consist, like the plant, of an organic and a mineral part, of which the former is usually much the larger in quantity. But a new branch of study is connected with the decay or decomposition of this vegetable matter, and especially of its organic part, in the farm-yard, in the compost-heap, or in the soil. This decay gives rise to new chemical combinations which have much influence on the efficacy of the decomposed matter as a manure. The nature and products of this new series of chemical changes ought not to be unfamiliar to the maker of useful and trustworthy experiments.

Those which are of animal origin resemble, of course, in composition, the parts of the animal body from which they are derived—the blood, the flesh, the bone, &c. Or, if they consist of the urine and droppings of animals, they have a certain relation, especially the solid excretions, to the food on which the animals have lived. Here, however, another new kind of information is demanded. These animal substances, like those of vegetable origin, putrify or decompose before they become directly useful to plants. In the bodies of animals, also, changes take place, by which the food consumed is decomposed, and new compounds of much importance are, in consequence, introduced into the urine and the droppings. All these changes are in some degree connected with the richness and fertilising quality of animal manures, or with the special action of the variety which may be used. To know on what the general efficacy or peculiar effect of such manures depends, their changes, and the substances produced by them, should be understood. How different samples of the same kind of manure differ in virtue; how this virtue is modified, lost, preserved, or augmented; these questions are of much consequence in ordinary farming, if the best or most profitable results are to be obtained by the practical man. But, in

experimental farming, in which not only distinct and definite, but comparative results are especially wanted, the means of answering them is indispensable. I shall have occasion hereafter to show that many of the experiments hitherto made in practical agriculture, and published as strictly comparative, and therefore safe guides for reasoning, are deprived of all trustworthiness and comparative value because of the entrance into them of the indeterminate element of farm-yard manure—a variable, indefinite, and constantly changing admixture of vegetable and animal substances.

Mineral or saline manures are combinations, or mixtures of different combinations, of one or more of those mineral substances which exist and are found in living plants. These saline substances are fixed and definite in their composition, and are admirably adapted for rigorous experimenting. But to use them right—to apply them in the proper place, at the proper time, and in the proper quantity—to understand their action, how they ought to be mixed, and why their effects vary in different circumstances and localities—all this requires that they should be thoroughly known, and their mode of action, as single substances and as mixtures, understood.

It will be seen, also, that no one of the several departments of knowledge we have adverted to, can guide us correctly of itself: they must be taken together. The composition of the plant and that of the soil must be taken in connexion with that of the manure and with the changes of which it is susceptible, if the mind of the experimenter is to be enabled to judge correctly of the effect of his applications to the land he cultivates—faithfully to register what he does and observes, and correctly to interpret his observations and results.

§ 3.—*General principles of husbandry—Knowledge of local and individual practice.*

It is supposed that the suggester is acquainted with the general principles of practical husbandry, and with the ordinary farm routine. But he ought also to know the most important specialties connected with the district or farm in or for which his experimental trials are specially recommended.

To the general nature of the soil, the local geology, the springs, &c., I have already alluded. But he should know also—

1°. The kind of corn and root, or other crops usually cultivated in the district.

2°. The rotation in which these crops usually follow each other, and the general reasons for its adoption.

3°. The manures usually employed; how they are prepared; when, and how, and how often, and in what quantity, they are applied.

4°. The state of cleanness, dryness, openness, &c., in which the land and crops are usually kept.

5°. How the rearing and feeding of cattle is understood: to what extent it is practised, and its influence upon the mode of manuring, and the consequent condition of the land.

6°. Even the tenure of the land and the size of farms are indispensable things to know.

Here are numerous points beyond the sphere of a mere chemist, whose mind must be greatly enlarged with kindred information before he can give safe experimental advice to the practical rent-paying farmer.

Of course, in the following work, which contains general suggestions for experiments in all localities, I cannot include such as are especially adapted to given districts and farms, as if I knew regarding them all the particulars above detailed. But persons of skill, to whom these circumstances are all known, will in each case select, from what this book contains, such recommendations or suggestions as appear most suited to the circumstances, and will modify them as these circumstances may seem to advise.

§ 4.—*Importance of local climatic knowledge.*

It will at once strike the reader that the bulk of the suggestions offered in the following pages must be suited especially, if not solely, to such climates as resemble generally that in which we live. But among ourselves there are great diversities of climate, the effect of which, in regard to experiments to be made on a particular spot, ought carefully to be considered;

and the more so when the results of these experiments are to be compared with those made in other localities. Thus—

1°. The annual fall of rain varies much. On the west coast of Great Britain and Ireland, exposed to the wide range of the Atlantic, it is greater than on the east coast; and among the mountains towards the west, as in Cumberland, it is still greater. The seasons at which the rain falls are also different in different localities, as well as the number of days on which it falls and the habitual clearness of the sky, on which the progress of vegetation so materially depends.

2°. Then the mean annual temperature of places differs much —the mean temperature of the several seasons—the maxima and minima—the periods when they occur—their duration, &c.

Altitude modifies these temperatures, (1° F. for 300 or 400 feet;) latitude modifies them, the neighbourhood of the sea, the proximity of mountains, and other circumstances.

3°. The direction and temperature of the prevailing winds; their duration; their intensity; their hygrometric condition; the consequent evaporative power of the place, and the degree of permanent moisture in the soil which mainly depends upon it; the frequency of hoar-frosts or blighting winds in spring;—

All these subjects together include a very wide field of useful meteorological knowledge. To the interpreter and reconciler of experimental results, this kind of knowledge is more immediately necessary than to the suggester or performer of the experiments themselves. But its connexion with experimental data and deductions is so intimate, that it must be consulted and taken into account by all those who desire to aid in establishing practical agriculture upon a scientific basis.

§ 5.—*Composition of the several parts of animal bodies, and how they are built up and sustained.*

To that department of husbandry which occupies itself with the feeding of animals, a familiarity with the composition and functions of the several parts of the animal body, and of the mode in which they are built up, or fed and sustained, is of great importance. By the experimental feeder these things ought to be well understood.

1°. All parts of an animal, the solid and fluid parts equally, like those of a plant, consist of an organic or combustible, and an inorganic or mineral portion. This organic part is composed, as in the plant, of the four elementary bodies—carbon, hydrogen, nitrogen, and oxygen; but, with the exception of the fat, the body of the animal, as a whole, is much richer in nitrogen than the substance of the plant. It is chiefly to this abundance of nitrogen that animal substances owe the peculiar phenomena that attend upon their decomposition or decay—such as the production of ammonia, the evolution of disagreeable odours, &c.

2°. The mineral matter of the animal body consists of the same substances as are found in the plant; and, as in the plant, they usually form only a small percentage of the whole weight of the several parts of the body. The bones form the only exception. In them, when dry, the mineral matter forms about two-thirds of the whole weight; while in other parts of the body it does not amount to more than from three to five per cent.

Phosphoric acid and lime are the main ingredients found in the mineral matter of the bones; and the importance of the bone to the animal may be regarded as a measure of the importance of these two substances to the animal economy.

The potash and soda are for the most part diffused through the fluids of the body. The silica, which appears so necessary to many plants, holds only a subordinate place in the animal. In the hair and nails it is met with in minute quantity, and in the feathers of birds. It is probably a necessary of life to most animals, though present in them only in small proportion, and for purposes as yet by no means well understood. The same may be said also of fluorine, about one per cent of which is found in the bones and in the teeth.

Consisting of the same elementary bodies as the plant, though in somewhat different proportions, it is not difficult to understand generally how the parts of animals are built up and sustained. The vegetable food conveyed into the stomach contains all the elementary substances of which the body is composed; and out of these the absorbing vessels select, we may say, what is wanted, and convey it to the part of the body where it is required.

But such a generality as this explains nothing. If it were necessary only to introduce the elementary bodies into the stomach of the animal, why make use of vegetable substances for the purpose? They might be swallowed at once as they occur in the soil, and animals might, to a great extent, become independent of vegetable life. But the relation, in regard to chemical composition, between the plant and the animal, is much closer than is represented by the above general explanation, and is, in reality, both beautiful and interesting. Thus—

1°. The animal body contains a variable, often a large, proportion of fat. The vegetable always contains a quantity of fat, sometimes identical with the fat of the body, and always closely resembling it. The fat of the plant, therefore, enters ready formed, and directly contributes to the increase of the fat of the body. Or if the plant do not contain a sufficient amount of fat to supply the wants of the body, other substances are present in it (wax, starch, sugar, &c.) which are more or less readily transformed into fat in their progress through the organs of digestion. Thus the animal does not deal with the elements (carbon, hydrogen, and oxygen) of which fat consists, but with chemical combinations already prepared by the plant, and which it slightly transforms if necessary, or conveys directly to the several parts of its body.

2°. So with the muscle of the animal. The gluten and other protein compounds of the plant—which also especially abound in young plants and shoots, and in seeds—are either identical with the muscular fibre, or differ from it in a very small degree, either in properties or in chemical composition. The stomach, therefore, extracts them at once, ready formed, from the vegetable food, as it did the fats, and they are subjected, if necessary, to a slight transformation only, before the vessels convey them to the parts of the body where they are required.

3°. The blood, as a whole, is almost identical in composition with the muscle of an animal. The same general relation, therefore, exists between the protein compounds of the plant and this part of the animal substance. From the food in the stomach they are extracted and conveyed at once into the

circulating blood, by which they are transported and diffused everywhere.

4°. Concerning the saline substances of the blood and other animal fluids, and the phosphate of lime of the bones, I need only add, that they exist in the plant in states of combination more or less similar to those in which they are found in the living fluids and tissues of the animal.

Thus, while the plant has, to a certain extent, to deal with the elementary bodies themselves, or with their more simple combinations, and to bind them up into those compound molecules of which its own parts consist, the animal begins with these compounds, turns and alters them a little if necessary, and at once fits them into their places. Each of the digestible constituents of a plant serves its appointed purpose. The protein compounds alone form muscle; the fat, sugar, &c., form the fat; and the substance of the bones comes at once from the phosphates in the plant.

This important general view must be our guide in all experiments in feeding. It must be attended to equally by the suggester, by the performer, and by the interpreter of such experiments.

§ 6.—*General functions of the animal body.*

The general functions of the animal body must also be considered in all experiments upon cattle. The most important of these functions are—

1°. *Respiration.*—The animal inhales atmospheric air, containing only a small proportion—two gallons in five thousand—of carbonic acid gas, and a little watery vapour. It expires air loaded with watery vapour, and containing nearly a hundred times as much carbonic acid—three or four gallons in a hundred.

The source and quantity of this carbonic acid are especially important. It is composed of carbon and oxygen, of which the former is derived from the food conveyed into the stomach, the latter from the air inspired by the lungs. The quantity of carbon thus thrown off from the lungs of a man varies from five to thirteen ounces in the twenty-four hours. In the case of the horse or the cow, it is five or six times as much; and in

that of the sheep or pig, it is somewhat less than is given off from the lungs of a man.

But the source of this carbon—the kind of food from which it is usually derived—is necessary to be understood. Starch, sugar, and gum consist of carbon and water (or its elements) only—one hundred pounds of each of these substances, by weight, on an average representing or containing forty-four of carbon. These substances, and especially the starch, form a very large proportion of all vegetable productions which are used for food either by man or by other animals; and the purpose served by them in the system, is to supply the carbon thrown off by the lungs during respiration. If this be their natural use, then their presence in sufficient quantity in the food becomes almost a necessity of nature.

The fatty substances and oils which occur in plants also contain much carbon united to hydrogen, and less oxygen than exists in starch. One hundred pounds of these fatty substances contain upwards of eighty pounds of carbon—weight for weight, therefore, they are capable of supplying the wants of the respiration for a much longer period than starch. It is believed that they really do, to a certain extent, supply carbon for respiration, and that this is one of the incidental purposes served by the accumulation of fat in the animal body. But that this is not intended to be the ordinary source of carbon, at least to herbivorous animals, is shown by the comparative scarcity of fatty matter in plants, and the abundance of starch, gum, and sugar.

2°. *Perspiration.*—Animals also perspire; and besides carbonic acid and a little nitrogen, saline, fatty, and other substances exude from the pores of the skin. In reference to this function, it is necessary to be borne in mind, that the means of a free perspiration are necessary to a healthy and thriving condition of the animal, and that the substances given off from the skin must be supplied by the food.

3°. *Digestion.*—Properly speaking, this function consists simply in the conversion of the nutritive parts of the food into a fluid form, and the absorption of them by the proper vessels which are to convey them to the blood. That the presence of free muriatic acid in the stomach is necessary to this resolution

of the solid food into a semi-fluid state, shows that the common salt of the food—from one of the constituents of which, its chlorine, muriatic acid is formed—is closely connected with a healthy state of digestion.

4°. *The building up* of the several parts of its body with the substances extracted from the food, is another important duty of the living animal. We have already seen that for this purpose the raw materials of which muscle, fat, and bone consist, are prepared by the plant, and conveyed ready formed into the stomach. These substances are extracted from the vegetable, and conveyed to those parts of the body which, because of their increasing size, require new materials, or to which they are necessary for the purpose of replacing that which is naturally removed.

5°. *Pulling down* we may familiarly call that function of the healthy animal body, by which its several parts are made to undergo a constant and gradual removal. No sooner are the parts of the body built up, even in the full-grown animal, than they begin to be taken down again. The portions as they are removed, or perhaps in order to their removal, are decomposed and carried off, to be rejected in the animal excretions. In three to five years every part of the body is removed and renewed in this way, and the nature and daily amount of this natural waste form fundamental considerations in all discussions or suggestions on the subject of feeding.

6°. *Excreting* is the final function exercised by the animal in reference to its food. What the stomach does not fully reduce to a fluid form, and all which, being so reduced, is not taken up by the absorbing vessels, passes downward along the alimentary canal, and is finally rejected either in the urine or in the solid excretions. That which is removed from the body itself, also, through the influence of the causes which produce the natural waste, passes off and is rejected in the same manner. And in reference to this, it is not unuseful to bear in mind, that the characteristic element of the muscles and cartilages, their nitrogen, passes off in the urine; while the equally characteristic ingredient of the bones, their phosphoric acid, passes off in the solid excretions. Carnivorous and omnivorous animals, only,

void a urine which contains a sensible proportion of phosphoric acid.

§ 7.—*Special structure of the digestive organs of different animals.*

Animals are beautifully adapted to the conditions in which they are intended to live, and to the food they are most likely to obtain, and most fitted to thrive upon. In so far as they are so fitted by the varied structure of their stomachs, the experimental feeder ought to a certain extent to make it a matter of study.

Purely chemical principles alone are not sufficient to guide the rearer of animals for profit. Chemistry says, give the animal so much protein (gluten, albumen, &c.) every twenty-four hours—so much starch or sugar, so much fat, so much of the material of bones, and so much saline matter, and all its wants will be abundantly supplied. But the comparative anatomist, and the animal physiologist, smile at these simple orders. In what form, he asks, *must* they be given—in which of many forms *may* they be given—of all these available forms, which is the best adapted to the structure and functions of the animal's stomach—which is likely to produce the most profitable return? The stomach of man is comparatively simple and one, and his alimentary canal of moderate size and length. The stomach of the horse is also simple or single, and smaller in proportion than that of man; but his bowels are capacious, showing that he is intended to eat, and therefore requires, food having a certain degree of bulk. "A horse could not live so well on oats, if fed entirely upon them, as when a certain portion of fodder is given. With them a certain quantity is required. But this may be carried too far, and the animal may have its bowels loaded with too large a quantity of unnutritious food."—(Dick.) The pig's stomach is also simple, and resembles most nearly that of the horse, while its intestines have a nearer resemblance to those of man.

The ox and sheep have compound stomachs, consisting of four compartments, usually spoken of as the four stomachs. These animals ruminate, or bring up their food from the paunch,

or first stomach, and chew it over again before they allow it to pass down to the lower stomachs. Animals with simple stomachs never ruminate. The intestines of these animals also differ in length from those of the ruminants. Thus, while those of the horse are ten times, and those of the pig sixteen, the intestines of the cow are twenty-two, and those of the sheep twenty-seven times the length of the body.

It must be obvious to the most superficial, therefore—

1°. That the same kinds of food, whatever be their chemical composition, are not equally adapted to the stomachs of all animals. And

2°. That the form in which the food is given, is nearly as important to an animal as its composition; and that, to produce the maximum effect upon each animal, this form should have a special adaptation to the peculiar structure of the digestive organs of that animal.

§ 8.—*General relations between the soil, the plant, and the animal.*

And when possessed of the several kinds of knowledge to which I have adverted in the preceding sections, the experimenter will find his task made more easy by the light which each of these branches throws upon the other. He will see that there is a natural and close relation between the soil, the plant, and the animal, which is not only simple and beneficial, but which is pregnant with useful practical instruction.

If nitrogen exists in, is necessary to, and by natural operations becomes fixed in the soil, it is because the plant cannot form its gluten and albumen without it. If the plant form gluten, it is that it may, as its last service, convey into the stomach the raw material, out of which the muscles of the animal are to be directly built up, and without unnecessary labour to the digestive organs. If food containing much of the gluten is remarkably nourishing, it is because on the full maintaining of the muscles the sustenance and strength of the animal chiefly depends. And if the urine promote vegetation in a high degree, it is because the nitrogen of the decomposed muscle is in large proportion contained in it.

Again, if the soil contain always common salt, which passes

into the plant, and if the immediate function of one of the constituents of this salt (its chlorine) in the plant is not understood, we see at least a reason for its presence in vegetable food, in the fact that muriatic acid, of which chlorine is an element, is indispensable to the process of digestion in the animal.

So, if iron be present in vegetable food, it is, among other reasons, because iron is a constituent of the healthy blood; and if manganese be detected in the plant in still smaller quantity, it is because this substance also, though in smaller proportions than iron, is constantly to be detected in the blood.

If the roots of plants stretch themselves widely through the soil, it is that they may pick up those substances which, like phosphoric acid, are present in the soil in minute quantity only, and yet are absolutely necessary to vegetable growth. And if this phosphoric acid accumulate, especially in the grain, it is because animals, which chiefly live upon grain, must obtain it in that food in sufficient abundance to supply with readiness the wants of the most rapidly increasing bones.

And if, again, all the chemical elements of a really nutritive food at one time accumulate in the seeds of plants, at another in their roots or leaves, and at another diffuse themselves throughout the whole substance of the plant, it is that each animal may be supplied with nourishment in that most appropriate form which is adapted to the special structure and digestive powers of its stomach and alimentary canal.

A thousand such close and striking relations, among all the departments of practical husbandry, will from time to time suggest themselves to the mind of the instructed man; and while they make his proceedings, especially those of an experimental kind, more interesting to him, they will also clear up many obscurities, and remove many difficulties out of his way.

The final impression I am desirous of leaving upon the mind of the reader, by all I have said in this preliminary chapter, is this,—that experiments by which truth is to be established, or from which natural laws or principles are to be deduced, cannot be hastily or ignorantly undertaken, or thoughtlessly, or without much care and anxiety, carried on. This remark, of course,

does not refer in its strictness to general farm experiments for private use, and with a view to economical ends only. Such experiments neither require the same preparation on the part of the experimenter, nor the same care and scrupulous accuracy in conducting the experiments. General results are often enough for such purposes, and a failure may be sufficient to deter, or apparent success to urge on, the practical man, though neither the amount nor the cause of either may be clearly understood.

§ 9.—*How analyses are corrected through the perception of such relations, and how we arrive at an exact knowledge of the composition of the plant, the soil, or the animal.*

I conclude this chapter by observing that the perception of such relations as are explained in the preceding section is not a mere intellectual gratification, or a help only to the practical man in his experiments—it directly promotes the progress of knowledge, suggests new experimental researches, and points out new methods of approaching the truth. Thus, in regard to our actual knowledge of the composition, absolute and comparative, of soils, plants, and animals, we have by no means been able to arrive at it, directly and at once. It is by the employment of two very different methods that it has been attained,—

First, by direct analysis of the soil, the plant, or the animal.

Second, by reasoning backward to the plant from the ascertained composition of the animal that feeds upon it, and to the soil from the composition both of the animal and of the plant.

Thus, in the plant, we are led to detect substances, and to determine their quantity, the essential or necessary nature of which to the plant itself we deduce only from the fact of their being always present in the animal in notable proportion. Such is the case with oxide of iron, with oxide of manganese, and with fluorine. The proportion of one or other of these substances which exists in a plant, is frequently so small that it would entirely escape detection, were we not urged to more close examination by a knowledge of its existence in the animal; or if it were detected, we should, without such knowledge of the animal, be inclined to consider it as only accidentally present.

And in the soil a skilful analyst might often pass over the minute proportions of potash, or of phosphoric acid, contained in it, were he not assured, by their presence in the plant, that he ought to find traces of them in the soil on which it grows.

The composition of the animal, also, is rectified and improved by similar reasoning in another direction. The soil and the plant, for example, both abound in silica, but analysis detected it in the parts of the animal body, in traces so minute, that they could not be regarded as necessary in any respect to its healthy growth. But in the feathers, the covering of birds, it was found to exist always in very considerable proportion; and hence, the hair, the covering of animals, being more minutely examined, silica was recognised to be always present in, and apparently necessary to it, in small proportion. Thus it ought also to be necessarily present in the blood, and in the other fluids, on its way to or from the hair, and farther research has shown this to be the case.

Thus our knowledge is in its nature progressive. Analyses of one kind or of one substance lead to rectifications in analyses of another kind, or of another substance. It is not by improved methods alone that our analytical results are made more perfect. Our eyes are sharpened when we learn what to look for, and with the same methods and skill we shall discover substances we had not previously attempted to detect. Not only does the composition of the animal tell us what must be in the plant, and in the soil, but, as the example above given shows, the recognised use and necessary presence of a substance in an animal of one class, may lead to researches which, contrary to received opinions, may show it to be necessary to animals of other classes also.

So it is with experiments in the field and the feeding-house. Those which I am about to suggest in the following pages will rectify past results and suggest new researches. The results of these, again, will send us back to revise our opinions and repeat our analyses; and thus, by the joint aid of the laboratory, the field, and the feeding-house, will scientific agriculture be carried slowly but steadily forward.

CHAPTER III.

How field experiments ought to be made. Form, extent, kind, and condition of the land. Precautions to be taken. What is to be observed and recorded. Quantity of land required for a continuous series of field experiments. Experiments should be made with a view to a definite object or end. Evils arising from badly conducted experiments. Why the results of analogous field experiments are often so discordant. Importance of ascertaining the limits of natural variation in the productiveness of an experimental field. Necessity of double experiments. Ought the mean of the natural produce of different parts of a field to be taken as the standard with which to compare the produce of experimental manured portions?

A COMPLETE and satisfactory answer to the question, How ought experiments in practical agriculture to be made? requires the consideration and discussion of a variety of particulars.

1°. Of the form, extent, kind, and condition of the land on which they ought to be made.

2°. Of the precautions to be taken in conducting experiments generally, and of those which are specially necessary in each of the different branches of husbandry.

3°. Of the purpose, immediate or remote, for which the experiments are to be made.

4°. Of the kind of observations which ought to be made during the progress or at the close of the experiment, and of the proper way of making and recording them.

I shall make a few observations on each of these points in their order.

§ 1.—*Of the form, extent, kind, and condition of the land on which experiments ought to be made.*

The *form* of the pieces of land on which field experiments are made ought to be square or oblong. Allotments of such

a form are more likely to be uniform in quality, are more easily measured with accuracy, are more compact, and fit more closely into each other. The plants grown upon them are more removed also from external influences.

The custom of making experiments upon two or more drills or rows of a crop is objectionable and untrustworthy. Among other reasons, it is so because the roots of plants stretch themselves laterally to considerable distances,—those of the turnip, for example, to distances of five or six feet. The outer rows or drills, therefore, are by no means beyond the influence of the adjoining soil or crop, or of any variety, superabundance, or scarcity of manure, by which the adjoining soil may be distinguished from that on which the experimental crop is growing.

2°. The *extent* of an experimental piece of ground is limited chiefly by the labour required to weigh the crop produced, which increases almost in equal proportion with the breadth of land employed. Where comparative experiments are to be made, a quarter of an acre, at least, should if possible be devoted to each. By this means, unobserved or accidental differences in the nature or condition of the soil, or in the quantity or quality of the manure applied to the several parts, which might materially affect the absolute produce of a smaller portion, will be in some measure eliminated, and more trustworthy comparative results obtained. This quantity, of course, may at any time be increased with advantage, and it may be somewhat diminished when the necessities of the case, such as the whole size of the field, or the extent of similar land at the experimenter's disposal, demand it, or the obvious and known uniformity of the soil, &c., seem to render an entire quarter of an acre unnecessary.

3°. The *kind* of soil, if it is uniform in quality, is of little comparative consequence, generally speaking. Whether rich or poor, light or heavy, it may be experimented upon, if its agricultural history and its chemical composition are known. The results obtained will of course be specific to the kind of soil. What is called a virgin soil, or one to which no manure has for a long time been applied, if within reach, should be

preferred for comparative trials, which are intended to test the special efficacy of different fertilising substances, as on such a soil their precise effects are likely to be more clearly and easily seen.

4°. But the *condition* of the soil selected is of much importance. Its richness or poverty in organic matter; its fulness of manure, or the contrary; the kind and quantity of manure added in past years, and the crops grown upon it; its clearness or freedom from weeds; its past history, in short, and its present treatment, are considerations from which its condition may be deduced, and which, when rightly weighed, will not only explain an apparently anomalous result when obtained, but will often demonstrate beforehand what the effect of this or that substance is likely to be.

It is not, as many have hitherto supposed, equally favourable or equally indifferent to all the substances we may wish to compare, whether we select this or that piece of land for our experiments. If twenty men are to be employed to dig a piece of land, the chance is the same to all, whatever be the nature of the land; and the quantity dug by each in an equally efficient manner, in a given time, is a fair measure of his comparative strength, industry, and skill. But it is very different with substances which are to be mixed with the soil, for the purpose of comparing their effects upon a growing plant, which requires a certain portion of each of them to enable it to build up its own stem and leaves. These substances contain, or are themselves, the very things which should or do exist in the soil itself, and it is only in proportion as one or other of them is deficient in the soil, in a state in which the plant can make use of it, that its influence becomes perceptible. The exact or absolute influence of a substance upon vegetation, or even its comparative influence, can only be estimated by experiments upon a soil in which one or all are equally deficient, or are deficient in known degrees, so that the quantity of each can be proportioned to this known deficiency.

But a practical and economical result is not so difficult to be arrived at as this precise theoretical one. If, when two substances are tried by the farmer upon his field under like circum-

stances, the one produces a striking and the other an insensible effect, the lesson to him is clear. In the present condition of his land, he ought to employ the one and reject the other. It matters nothing to him whether the difference arise from the actual scarcity of one of the substances in his land, and the abundance of the other, or from some other cause. To the seeker of the absolute truth it may be of moment, but the profit of the farmer of that given kind of land, in the given condition, is independent of this more refined inquiry.

§ 2.—*Precautions to be adopted in making experiments in husbandry.*

Among the precautions to be adopted by the rural experimenter, the following may be mentioned:—

1°. That everything should be done by weight and measure. In field experiments, the land should be accurately measured, and the substances applied, and the produce reaped, exactly weighed. Weight and measure should equally prevail in all dairy and feeding experiments; and on no occasion should any quantity, upon which future proceedings or reasoning is to be based, be guessed at or estimated approximately.

2°. That both the chemical composition and the physical qualities or condition of all substances employed either in feeding or in field experiments, should be accurately ascertained and recorded. In all field experiments this should, as much as possible, be the case. In experiments upon feeding, however, a certain latitude may be allowed in the use of vegetable produce—such as hay, beans, oats, turnips, &c.—of which the average composition may be ascertained, at least approximately, in books upon scientific agriculture.

3°. Two experiments of the same kind, one to check the other, should always be made. In field experiments, the two plots devoted to the same experiment should be as far removed from each other as is convenient, with the view of getting rid of the influence of soil, exposure, &c., which, though unperceived, may yet sensibly modify the result of any given appli-

cation to the land. Thus, if four substances, 1, 2, 3, 4, are to be tried on as many quarter acres, a square or oblong of two acres might be subdivided as follows :—

1	2	3	4
3	4	1	2

1	2
3	4
2	1
4	3

§ 3.—*What observations ought to be made, and how.*

In all experiments, the immediate, as well as the ultimate, effects and appearances should be observed and recorded. At intervals, also, between these two periods, the effects and appearances should be examined and noted down, as these intermediate observations are often very instructive. Important changes of weather should likewise be registered. In field experiments, the weather which may promote the action of one substance may diminish that of another. In feeding, also, the temperature is an element in which extreme oscillations not only affect all animals, but which influence some animals more than others, and thus modify the action of the food they eat.

These observations should not only be all made with much care and conscientiousness, but they should, as far as possible, be made by the chief experimenter, and recorded by himself. He ought, also, to guard against the possible influence of any preconceived opinion, whether theoretical or professional, which may insensibly act upon his mind.

The most enlightened and the best educated are not free from the possibility of such a bias. And, in regard to such a possible bias, practical men are exceedingly suspicious, especially when deductions, in reference to practical subjects, are drawn by scientific men. Hence they receive, with doubt and coolness, the recommendations of science—supposing the man of science, if not ignorantly prejudiced, to be professionally influenced in

favour of his own theoretical views. For a similar reason, they listen with suspicion to details of experimental results obtained by persons whose character or profession is in any way suggestive of doubt, or of a want of familiarity with practical operations. Thus, the fact that Mr Lawes is himself a manufacturer of chemical manures, has led some—unjustly, I believe—to detract from the value or trustworthiness of the field experiments and analytical researches made upon his farm in Hertfordshire. And, in like manner, in the neighbourhood of Lille, where Kuhlmann is also a manufacturer of manures, the experiments made under the direction, and published by this gentleman, have, as I gathered upon the spot, been followed by little practical benefit. The knowledge possessed by these practical chemists, and their familiarity with the subject, in reality make them more qualified than others both to suggest and to superintend experiments in the field, whether comparative or absolute. The results they publish, therefore, ought to be received and confided in at least as implicitly as those of other parties.

Still, it is much to be wished, not only that field and other experiments in husbandry should be extensively undertaken, and that they should be skilfully and conscientiously performed; but that persons should be employed upon them, to whose results no breath of interested suspicion could by any one be imagined to attach.

§ 4.—*Quantity of land required for a continuous series of field experiments.*

This inquiry may be considered of interest, in reference either to the performance of experiments, year by year, upon an ordinary farm of some extent, or to the establishment of what may be called an experimental farm or garden, in which experimental culture only is to be carried on.

In regard to the former, it is sufficient to observe that there appears no necessity for having a special portion of land set apart for experiments, since, year by year as the crops are changed, a convenient part may be chosen, which, because of

its being different every year, may better fulfil all the conditions which appear necessary to the utility and accuracy of the results.

But, in regard to a purely experimental piece of ground, two considerations tend to throw some light upon the extent in acres which it ought to include.

1°. Land experimented upon ought to be in a uniform, natural, and well understood condition. That is to say, its agricultural history and past treatment should be well understood, and the portions reserved for after experiments should be kept in a similarly well understood condition.

2°. A second experiment must not be made on the same spot, except as a sequel or continuation of a former one, until several years have elapsed. By such a lapse of time, all appreciable action of the first application may in most cases be expected to be removed from the soil.

Now, suppose thirty-two field experiments, eight of each of four crops, to be conducted yearly over as many quarter-acres of land, this would require eight acres in arable culture; and, suppose five years to be necessary in order that the influence of the first application may die away, this period of time may elapse before a new experiment could be commenced on any one of the above plots. Thus five times eight, or forty, acres of a given quality of land—or eight acres of each of five different qualities—would be the full extent of arable land which such a farm or garden would require. A considerable proportion of this land would probably always be in grass, yet ten or twenty acres additional of old grass-land would be necessary for experiments to be made either upon itself or upon cattle or sheep to be in part supported by it.

No one, who considers how much thought and attention will be required by each experiment, made with a view to truth alone, and how numerous the secondary or subordinate experiments which would accompany the principal ones—and who adds to these the experiments on the feeding and rearing of stock, and the analytical researches which must accompany all the experiments throughout the whole year—will fail to see that from forty to sixty acres of land so employed would give ample occupation to any two skilful, industrious, and clear-headed men,

who, with proper assistance, might be willing to devote themselves to this most hopeful means of advancing scientific agriculture.

It is not my purpose here to advocate such an establishment, but practical agriculture might most profitably tax itself for the maintenance of at least one such experimental garden in each of the main agricultural, climatic, or geological divisions of our island.

§ 5.—*Experiments should be made with a view to a definite object or end. Evils arising from badly conducted experiments.*

Among the philosophical chemists of the past century, none was more zealous and more assiduous in original experimenting than Dr Priestley. Yet he is described by high cotemporary authority as *groping* after novelties. To experiment in the hope or on the chance of stumbling upon something new, without a definite and special end or purpose, is to grope in the dark, and cannot lead straightforward to any important truth. Much of the agricultural experimenting hitherto performed has been of this groping character—performed without a clear idea of the point or points to be made out or established by it. All experiments, therefore, ought to be contrived and executed—

1°. With a view to a definite object; to throw light upon some special point; to remove some doubt, or to solve some recognised practical or theoretical difficulty.

2°. This object should be one which the person to whom the execution or superintendence of the experiment is intrusted can clearly understand. The conductor must also comprehend the nature of the precautions necessary to secure sufficient accuracy in the result, why these precautions are necessary, and the parts or points in the observations made, or results obtained, to which the greatest importance attaches. Thus, while much knowledge and a clear conception are required in the designer of an experiment, no little cleverness, also, and precision, are indispensable in the conductor of it.

3°. All experiments must be comparative. If the effect of a certain influence—of a special manure, for example—is to be ascertained, that effect must be compared with what is seen

upon another spot to which this manure has not been applied. But to ascertain the precise effect of this one influence, every other influence likely to modify it must be excluded. This is a requirement of vital importance—one exceedingly difficult to be attained; which requires attention to many circumstances; which has been very frequently neglected; and which, as I shall hereafter show, has not only led to very discordant results in different places, but has greatly lessened the value of nearly all the field experiments that have hitherto been published.

The reader will see the necessity of not only accurately observing and recording results, but of tracing and attributing them to their precise causes, if he considers the evils that flow from the publication of experimental results which have not been carefully attained. Thus a badly made or imperfectly observed and criticised experiment, is not merely time and money lost, but it leads—

1°. To the adoption and introduction, among our received views and into our standard books, of incorrect results, and of erroneous deductions and opinions. Thus error is perpetuated, and becomes every day more widely spread, and more difficult to be afterwards removed or eradicated.

2°. To loss of money in practice by the evil advice it gives. Practical men, for example, who are ill able to afford it, may be induced by a published result to expend money on manures, or on methods of improvement, which, in their circumstances, are unworthy of attention, and can only lead to loss. Every one who is at all interested in the art of husbandry will see the economical importance of this observation, and will in all probability recollect cases in which such loss has actually been sustained.

3°. To the neglect of further researches or experiments of a similar kind, on the part of purely scientific agriculturists. The belief that a thing is already done — that certain published experiments have explained or established it—is a sure bar against further inquiry; and a belief of this kind has caused important theoretical principles to encumber our works upon scientific agriculture, and, to a certain extent, to guide our practice for many years, which more accurate experimental

research has afterwards shown to be utterly void of foundation. Thus, by incorrect experiments—instead of being promoted, as by such trials it ought to be—agriculture, both as a science and an art, is materially restrained, and the attainment of truth hindered and delayed.

§ 6.—*Why the results of analogous field experiments are often so discordant.*

That the results of analogous field experiments have often been so discordant—the effects of the same manure, for example, in different fields or localities, found to be so very different—has to some been a cause of much discouragement, while to others it has served as an argument against the utility of experimenting altogether. The reader of the preceding sections will easily see how such discordances must have been almost unavoidable, as experiments have hitherto been conducted. They may have arisen from the action of one or more of the following causes:

1°. Because true averages of the natural productiveness of the field, or the limits of natural variation in the crop, have not in each case been determined; and thus the true effects or differences in the amount of crop, caused by a given application, cannot have been ascertained.

2°. Because the original nature of the soils—their physical character, that is, and their chemical composition—may have been different in the several experiments.

3°. Because the previous cropping or manuring, or generally the agricultural history of the pieces of land, may have been different—thus establishing very influential artificial differences between soils originally alike.

4°. Because the quality of the substance, the period of applying it, the manner and form in which it is applied, the state of the weather at the time, or the state of the crop when the applications were made, or that of the season afterwards, may not have been in each case equally favourable.

5°. Because a difference in the variety of the same crop grown in two places, or in the time of gathering or lifting it, may have affected the results.

Some of these causes of discordance deserve a more special consideration.

§ 7.—*Importance of ascertaining the limits of natural variation in the productiveness of an experimental field. Necessity of double experiments.*

No adequate or satisfactory consideration has yet been given to the question—When are results to be considered as identical? I have elsewhere* drawn attention to the importance of this question, and endeavoured to show how the neglect of it alone throws doubt on most of the experimental results hitherto published. A farmer divides his field into four parts: to one he applies nothing, but to each of the three others he applies a certain quantity of three different substances. From No. 1 he reaps a certain amount of crop, and from each of the others an increase greater or less according to the substance applied. It has been usual to ascribe the differences between the crops on each of these latter and the crop of No. 1 to the effect of the substance applied—to measure the several effects of these substances by the several differences observed. Is such a mode of procedure correct? Are the inferences or measurements likely to be just? Experience, I think, gives a negative answer to these questions. Thus—

1°. In 1843, Mr Dockar, of Findon Farm, Aberdeenshire, made experiments upon turnips (green-topped yellow) with and without manure. From two separate eighths of an acre of the same field, to which no manure had been applied, he obtained at the rate of (tops and tails excluded)†—

First portion, . .	8 tons 11 cwt. per imperial acre.
Second portion, . .	6 ... 16 ... ...
Difference, . . .	1 ton 15 cwt., or $1\frac{3}{4}$ tons on a crop of $6\frac{3}{4}$ to $8\frac{1}{2}$ tons.

2°. At Barrochan, in Renfrewshire, from two unmanured

* *Journal of the Royal Agricultural Society*, IX. p. 200.

† *Transactions of the Highland Society*, July 1845, p. 7.

eighths of an acre of the same experimental field, Mr Fleming obtained, of early Liverpool yellow turnips, at the rate of—

First portion, . .	12 tons 17 cwt. per imperial acre.	
Second portion, . .	11 ... 8	
Difference, . . .	1 ton 9 cwt., or about ⅛th, or 12½ per cent of the whole crop.*	

3°. Mr Chalmers of Monkshill, in Aberdeenshire, from two un-manured eighths of an acre of grass-land, obtained of hay respectively—

First portion, . .	385 stones.
Second portion, . .	281 ...
Difference, . . .	104 stones,—equal to two-fifths of the smaller crop, very nearly.

4°. So at Erskine, in Renfrewshire, an experimental grass field, cut for hay, yielded, from each of two quarters of an acre respectively—

First portion, . .	838 lb. of hay.
Second portion, . .	726 ...
Difference, . . .	112 lb., or 1-7th of the whole.

From these results it appears that, upon land in an ordinary condition, two portions of the same field—supposed to be equal in quality, and for that reason selected as especially fitted for experimental trials—may naturally yield very considerable differences of crop, even when no manure is added to them.

It should also be borne in mind, that a single difference between two experiments made on the same field, cannot be safely regarded as an index of the maximum differences which the several parts of the field would be found to yield. When we make two experiments on a field, we find a certain difference between the two results. But if we had made a third, a still larger difference, compared with one of the other two experi-

* Appendix to my *Lectures on Agricultural Chemistry and Geology*, 1st edit., p. 56.

ments might possibly have been obtained. So that all we as yet know is, that different portions of a field, apparently uniform in quality, may yield returns in corn, roots, and hay, which differ much from each other. We have as yet no experiments from which we can deduce the limits of such differences in any soils.

Again, when the same manure is added in equal quantities to different portions of the same field, we have upon record differences even greater than those observed upon un-manured land. Thus—

1°. In the same field of Mr Dockar of Findon, mentioned above, and in the same season, two-eighths of an acre, dressed each with 20 bushels of bone-dust per acre, gave at the rate of—

First portion, . .	11 tons 9 cwt.
Second portion, . .	8 ... 14 ...
Difference, . . .	2 tons 15 cwt., or ¼th of the whole.

How is such a difference to be explained? Is it all due to previously existing differences in the quality of the soil? or did the bones act differently on the two parts of the field?

We have already seen that, without manure, two portions of this field differed in produce by 1¾ tons. But here, when the bones were added, the difference between two other portions became 2¾ tons. Was the previously existing natural difference really greater between the two portions of the field to which the bones were applied? or was the natural difference exalted —in some way, more brought out—by the action of the bones? or was there some cause in operation—such as a greater degree of moisture in one of the portions of land—which caused the bones actually to produce a greater effect on the one than on the other? The last supposition is by no means an unlikely one; but we have no data for determining whether any such cause really existed, or, if it did, how much of the observed difference of 2¾ tons was owing to this cause, and how much to original dissimilarities in the soil.

2°. From four plots of red wheat, dressed two and two with

59½ and 86 stones of rape-cape respectively, there was reaped per imperial acre—

	Rape-cake applied.	Market corn.	Weight per bush.	Light corn.
a First plot, .	59½ stones.	26 bush.	52¼ lb.	46 lb.
Second plot, .	59½ ...	21 ...	50½ ...	67 ...
b First plot, .	86 ...	28 ...	53¼ ...	35 ...
Second plot, .	86 ...	22 ...	51 ...	91 ...*

So that, in these two cases, there was a difference of five bushels an acre in the crop, and two pounds on the weight per bushel, from twice two portions of the same field similarly treated.

Here, also, we have no means of knowing how much of the difference was owing to original differences in the soil, which the eye cannot detect, and how much to differences in the mode of action of the manure.

3°. But the effect of similar applications is not only different in amount on many occasions, it is also different in kind. Thus Mr William Murray, at Slap, in Aberdeenshire,† obtained from two several eighths of an acre, manured with 20 bushels of bone-dust, the following weights of turnips, with and without tops and tails, per imperial acre—

	Gross weight.	Bulbs, topped and tailed.
First portion, . .	13 tons 11 cwt.	8 tons 3 cwt.
Second portion, .	13 ... 1 ...	10 ... 10 ...
Difference, . .	10 cwt.	2 tons 7 cwt.

Thus the relative weights of the tops and tails, and of the bulbs, in the two portions, was at the rate, per imperial acre, of—

	Tops and tails.	Bulbs.
First portion, . .	5 tons 8 cwt.	8 tons 3 cwt.
Second portion, . .	2 ... 10 ...	10 ... 10 ...

We can hardly avoid concluding, that in this case an original difference in the soil of the two portions must have caused the one to run so much to top; in other words, to continue to grow so much longer, and to be so much later in bulbing, than the other. The gross weight of the crops was nearly equal, but

* *British Husbandry*, i. p. 412.

† *Transactions of the Highland Society*, July 1845, p. 7.

the weight of bulbs differed by 2 tons 7 cwt., or one-fourth of the whole gross weight of the crop.

When differences so wide as those observed in the numerous cases cited in the present section are likely to be met with, it is quite clear that the result of no single trial can be regarded as an indication of the exact or absolute effect of a given substance upon a given crop in a given soil. Two or more experiments must in each case be made, if any trustworthy or useful determinations are to be obtained. Other illustrations of this position will find a place in the subsequent sections.

§ 8.—*Ought the mean of the natural produce of different parts of a field to be taken as the standard with which to compare the produce of experimental manured portions?*

But in what way are the results of the two or more experiments we may make to be regarded? Are we to take the mean or average result of the whole, and to consider this as an expression of the absolute natural productiveness of the land where nothing is applied to it, or of the absolute effect of this or that substance which we may have laid on? Or are the results of the several experiments of each kind to be compared each with each, and the absolute effects to be deduced according to some other method. For example,

Suppose three several portions of a field of wheat to yield, without manure, at the rate of 18, 21, and 24 bushels of grain respectively, the mean being 21 bushels—and that a fourth portion, to which a certain manure is applied, yields also at the rate of 24 bushels, are we to compare this last result of 24 bushels with the mean 21, and infer that the substance applied increased the crop by 3 bushels; with the number 18, and infer that it had increased it by 6 bushels; or with the number 24, and say that the application had done no good at all? In such a case as this, the reader will, I think, agree with me that no conclusion can be drawn as to the effect of the substance applied, inasmuch as the crop it produces is not greater than one portion of the field had produced without any application.

This reasonable conclusion has an important bearing upon the value to be attached to many series of otherwise praise-

worthy and laboriously conducted experiments, the results of which have been published of late years. Thus—

1°. In a series of experiments made by Mr Gardiner at Barochan, in Renfrewshire, in 1844, upon the effects of various substances applied as a top-dressing in spring to oats, (sown upon land trenched with the spade out of a nine-year-old lea,) we find, among others, the following results:—*

	Produce per Imperial acre. Grain.	Straw.
No dressing—average of four portions,	6 qrs. 3 bush.	$30\frac{1}{8}$ cwt.
Rape dust, 5 cwt. . . .	6 ... 3 ...	$39\frac{1}{8}$ ...
Sulphate of magnesia, 2 cwt., .	5 ... $7\frac{1}{4}$ ...	$28\frac{1}{4}$ ...

Now, as the results are here stated, it would appear that the rape-cake added nothing to the produce of grain, though it gave nearly half a ton more straw, and that the sulphate of magnesia actually diminished both to a large extent. But if, instead of the mean of the four undressed portions, the produce of each of these four had been recorded, we might possibly have found that one of them was smaller both in grain and straw than that of the portion to which the sulphate of magnesia was applied; while in another, the straw might have been as heavy as that which the rape-cake portion yielded. And if so, the inference to be drawn from the table as it stands, that the substances applied were in the one case really hurtful, and in the other only doubtfully beneficial, would not even have been suggested. It is not wonderful that land trenched from a nine-year-old lea should give a good crop of oats without assistance, and that it should be little in want of salts of soda and magnesia; but such tables as the one from which the above results are taken, do not satisfactorily prove it.

Had there been four separate experiments made with each of the substances, then the means of each set being taken and compared together, a very satisfactory result might have been obtained. As yet we do not possess any such system of mean results, though few things would at present do more to clear up our ideas as to the precise influence of this or that substance on the growth of plants.

* *Transactions of the Highland Society*, 1845, p. 421.

CHAPTER IV.

Influence of the varying quality of farm-yard manure on the results of experiments in which it is one of the substances employed. Influence of the previous treatment of the land. Influence of one substance in counteracting the beneficial action of another. Influence of the time and manner of the application of a manure, and of the period at which a root-crop is lifted. Influence of the physical condition of a substance in its state of chemical combination, and its tendency to decompose in a given soil. Influence of different varieties of seed. Influence of seasons on the results of field experiments. When experiments are to be rejected. Value of contradictory and of positive and negative results. Is it desirable that experiments in practical and scientific agriculture should be extensively made?

§ 1.—*Influence of the varying quality of farm-yard manure on the results of comparative experiments, in which it is one of the substances employed.*

NOTHING is better known than the varying quality of farm-yard manure. Not only does it vary in fertilising value on different farms, but upon the same farm also, and in some degree in the same dung-heap; so that we cannot expect from equal weights of it at all times the same amount of effect in causing crops to grow even on the same land. Supposing the nature of the soil, therefore, to introduce no cause of diversity of the kind adverted to in the preceding sections, this varying quality of the farm-yard manure must influence in a greater or less degree the results of every experiment in which it is made to play a part, and must make the results of it open to suspicion. Experience proves the correctness of this inference. Thus—

1°. Mr Dockar, at Findon, some of whose experiments I have already quoted, applied 20 loads of farm-yard manure to his experimental turnip-field in 1843, and obtained from two measured eighths of an acre at the rate of—

	Gross weight.	Bulbs, topped and tailed.
First portion, .	10 tons 11 cwt.	8 tons 18 cwt. per imp. acre.
Second portion,	8 ... 2 ...	6 ... 16 ... ...
Difference, .	2 ... 9 ...	2 ... 2 ... ...

Of course we cannot say how much of this difference may have been owing to the soil, and we can only infer that the manure may have, in part at least, been the cause of it.

2°. In an experiment of Mr Murray's, made at Slap, I find a nearer approximation in the crop on two portions manured alike with 20 tons of farm-yard manure—the one yielding 13 tons 10 cwt., and the other 14 tons 7 cwt. gross weight, and 11 tons 14 cwt., and 12 tons 6 cwt. respectively of bulbs. The difference here in the gross weight is only 17 cwt., and in the bulbs only 12 cwt., or about 5 per cent on the whole crop.

I find on record very few duplicate experiments with farm-yard manure alone, but there are several in which it was applied along with other substances, which, being of definite composition, may be supposed to be of definite action. Thus—

3°. On the same experimental turnip-field of Mr Murray, two portions (one-eighth of an acre each) were manured alike at the rate of 10 tons of farm-yard manure, and 10 bushels of bones, decomposed by sulphuric acid, with the following results:—

	Gross weight.	Weight of bulbs.
First portion, .	18 tons 7 cwt.	15 tons 17 cwt.
Second portion, .	15 ... 8 ...	13 ... 5 ...
Difference, . .	2 ... 19 ...	2 ... 12 ...

In two other experiments on the same field, made with the dissolved bones alone, the separate pieces of land gave precisely the same return both of tops and bulbs, (10 tons 18 cwt. gross.) It is reasonable, therefore, to suppose that, when applied along with farm-yard manure, the fertilising action of the dissolved bones was also the same in both portions, and that the large difference in the crops was due mainly to unobserved differences in the quality of the farm-yard manure applied to them.

4°. But a more striking difference of this kind is recorded among experiments made on the farm of Kerrytonlia, in the

Isle of Bute, in 1847. Three portions of the same field manured alike at the rate of 24 carts of farm-yard dung, and 16 bushels of bones per acre, gave respectively 34¾, 32¼, and 27½ tons of Swedish turnips. The differences, therefore, were—

Between the 1st and 2d portions, 2½ tons.
... 1st and 3d portions, 7¼ tons.

Some of this enormous difference of 7 tons must be ascribed to a natural difference in the quality of the soil on the several experimental plots, but some of it may fairly be ascribed also to the unlike quality of the farm-yard manure applied to the several portions, and to its consequent unlike action upon the bones.

I might select from the materials now before me many other experiments which lead to the same conclusion: and if such differences may exist in the quality of the manure made on the same farm, much more may it be the case with that of different farms. Hence the reason why in some cases—that is, on some farms—an admixture of sulphate or of nitrate of soda, or of sulphate of ammonia, with the fold-yard manure, made a sensible increase of the crop; in others no appreciable benefit seemed to follow from the addition; while in others, again, the produce was actually diminished. The admixtures being the same, such differences might be ascribed altogether to the unlike qualities of the manure employed, were it not that the soil in the different cases might have varied also, and thus have produced differences in the results, which we have no means of estimating. As in so many other published experiments, we have two disturbing causes, and only one result out of which to extract the precise effect of each.

§ 2.—*Influence of the previous treatment of land upon the results of field experiments. Long-continued action of bones.*

Every practical man knows that the previous treatment of a field or farm, the kind of cropping and manuring to which it has been subjected in former years, has an important influence upon its fertility at any given time. Such previous treatment may materially affect the results of experimental trials made upon the land.

The effect of bones applied for the first time is not forgotten

by grass land for thirty years, and the effects of a first application of lime are often visible for an equal period. An experiment made by Mr Russell at Kilwhiss in Fife, enables me to illustrate the way in which such applications long ago made, and perhaps forgotten, may seriously interfere with and modify the results of field experiments.

Of two fields, apparently identical in quality, and adjoining each other, and on which the experiments were made, the one had been boned with twenty bushels of bones thirteen years previous to 1841. In 1842, both fields were manured at the rate of ten loads per acre of farm-yard manure of good quality, and sown with turnips. On the *old-boned* field, the crop was *four times as bulky* as on the unboned field. In 1843, a crop of barley was taken from each after the turnips, and the crop on the two parts averaged, per imperial acre—

	bush.	lb.	Weight per bush.	Sold for
On the old-boned land,	36	14	57 lb.	28s.
On the unboned, .	31	19	56 lb.	27s.
Difference, .	4	51	1 lb.	1s.

So that, after fifteen years, this old-boning caused a large increase both in the turnip and in the corn crops. And had comparative scientific experiments been made upon the two fields, there is every reason to believe that results, by no means due to the substances applied, would have been obtained from that to which the bones had been so long before given.

Such invisible differences no doubt often exist among cultivated soils,—differences so minute, that even chemical analysis cannot discover them, though their effects may be visible upon the crops.* To a new tenant, the historical treatment to which

* Suppose a bushel of bones to weigh 50 lb., then a dressing of 20 bushels adds 1000 lb. of bones to the acre. To a soil six inches deep, this is in the proportion of 0.06, or $\frac{1}{16}$ of a per-cent,—less than an ounce to 100 lb. of soil. But of this bone only one-half (0.03 per cent) is mineral matter, which can be detected, and which is likely to remain for a length of time in soils of ordinary lightness. This proportion is very minute and difficult to detect, suppose it all to be in the soil; but how much more difficult must it be to determine the amount of this bone which remains in the soil after the lapse of fifteen years, when so much of it has been taken out by the crops, has sunk into the subsoil, or been washed out by the rains.

they are due may be unknown, and thus he may himself be misled in reporting the results of experimental trials. From the operation of disturbing causes, such as I have now illustrated, his results may not only be in discordance with those of others, but may be absolutely inexplicable.

The influence exercised upon the true and natural action of one substance by the presence of other substances in the soil, is illustrated by another experiment made by the same Mr Russell. He manured an entire field with twelve loads of farm-yard manure per acre, and applied to separate portions of his crop of green-topped yellow turnips, bone-dust, sulphate of soda, and a mixture of the two, with the following results:—

Dung alone gave	4 tons	2 cwt.	of bulbs.
Do. with 640 lb. of bone-dust, . .	6 ...	12	...
Do. with 200 lb. of sulphate of soda, .	4 ...	2	...
Do. with 640 lb. of bones and 200 of sulphate,	7 ...	7	...

Here it is seen, that while the addition of sulphate of soda alone to the dung produced no sensible effect on the produce of bulbs, its presence along with the bone-dust and dung together gave a larger crop than the bones and dung alone had given. Both the crops and differences in this case, however, are so small, that I do not quote them as worthy of much reliance, or as actually proving anything, but only as illustrations of the kind of effect which comparatively small quantities of substances in the soil may produce. They may cause apparently inexplicable diversities, which may tend to dishearten many, and to deter them from continuing to prosecute experimental field-researches.

In selecting land for experimental trials, therefore, too rigorous an inquiry cannot be made into its previous agricultural history. On naturally poor land, scientific experiments may be made with safety, and with the prospect of generally useful results, but on land which has been exhausted by mismanagement, the kind and extent of which may be only partially known, locally useful and interesting experiments only can be undertaken.

And, viewed as an economical question again, the application of saline and other substances, single or mixed, as top-dressings

to our cultivated crops, must be made upon soils which are "*in fair order.*" It is stated by Mr Main, as the result of his trials, "that if other circumstances, such as weather, &c., conspire to injure a crop, and at the same time the soil wants condition, top-dressing will not be followed with satisfactory results." And this is only expressing, in the language of a practical man, the scientific truth, that to enable any plant to grow well, all the materials it requires must be placed within its easy reach.

§ 3.—*Influence of one substance in counteracting the beneficial action of another.*

This point, though closely connected with the subject of the preceding section, is interesting and important enough to deserve a separate consideration.

I shall have occasion hereafter to show, that certain mixtures of saline substances applied to the land, act, generally speaking, in a more favourable manner than any of the same substances applied singly. This is consistent with our theoretical knowledge, and is readily enough explained. But such experiments as we at present possess seem to show that some substances, when applied together, may produce a less effect than one or other of them applied singly. Thus in some experiments upon wheat, made under the direction of Lord Blantyre, at Lennox Love, rape-dust, common salt, and sulphate of soda were applied singly, and in conjunction, with the following results:—

	Increase per acre.	Decrease per acre.
Rape-dust, 16 cwt. per acre, gave .	3½ bush.	—
Sulphate of soda, 1 cwt. . .	—	9¼ bush.
Common salt, 1 cwt.	—	1¼ ...
Rape-dust and sulphate, ½ of each,	—	3 ...
Rape-dust and common salt, ½ of each,	2⅓ ...	—

In these results it appears that the natural good effect of rape-dust was lessened considerably when mixed with the given weight of common salt, and that the influence of sulphate of soda for evil was able to overcome entirely that of rape-dust for good, and to cause a loss instead of a gain on the whole.

Now, these experiments are far from being conclusive: they are only suggestive of further inquiry, by more extended and more carefully conducted experiments on different soils, and in varied seasons and circumstances. But they seem to indicate that the presence of a comparatively small quantity of saline matter—of common salt or sulphate of soda, for example—in the surface-soil, may entirely overcome and mask the natural effect of such substances as rape-dust when applied in certain proportions. If such an influence of saline matter be possible in any but very dry seasons, it must in many soils be constantly exercised, and is deserving of the careful consideration of those who concern themselves with the deductions which may be fairly drawn from experimental investigations in the field.

Rape-dust and saline substances are both favoured by moist seasons. To the latter, moisture is necessary in a greater degree than to the former; and if such evils as the above can follow from their common presence in the soil, we should expect them only or mainly in very dry seasons. But the subject deserves to be investigated by careful experiment; and in a future chapter I shall suggest such field-trials as appear to me likely to throw light upon it.

§ 4.—*Influence of the time, manner, and form of its application on the apparent effect of a manure; also of the period at which a root-crop is lifted.*

1°. *The time.*—There are various points connected with the time of the application of a fertilising substance which are deserving of consideration. Thus,—

a At what season of the year it should be applied.—It has been found by experiment, that in the same season, and on the same field, gypsum applied as a top-dressing to young clover produced less effect when it was laid on in March than when it was spread in April.* But the subject of the most economical period for the application of different substances to different soils and crops has not as yet been made a subject of careful experiment.

The only series of experiments with which I am acquainted,

* See my little book *On the use of Lime in Agriculture*, p. 207.

which has been made with the view of throwing light upon this point, was performed in 1847 by Mr Alexander Main, at Whitehill in Mid-Lothian, and their results have been published in the *Transactions of the Highland Society* for March 1849, p. 530. He applied Peruvian guano, African guano, and saltpetre refuse,* in equal quantities of two cwt. per acre, to different portions of the same crop of Taunton-Dean wheat. To three portions the substances were applied on the 1st of February, and to three others on the 30th of April, with the following results per imperial acre :—

	Applied 1st February.		Applied 30th April.	
	Grain.	Straw.	Grain.	Straw.
No application, .	27½ bush.	19¼ cwt.	...	...
Peruvian guano, 2 cwt.	29½ ...	24 ...	29½ bush.	28 cwt.
African guano, 2 cwt.	27⅓ ...	24 ...	27 ...	27½ ...
Saltpetre refuse, 2 cwt.	27½ ...	26½ ...	33¼ ...	31 ...

In regard to the guanos, it does not appear from these experiments that the delay of three months had any other effect than slightly to increase the growth of straw. Where straw is usually short, therefore, a later application of guano is suggested by these results.

As to the saltpetre refuse, an increase of six bushels of grain, as well as four cwt. of straw, seems to imply that in the soil and locality of Whitehill a later application of this substance is likely to be the more profitable.

At the same time, I am forced to regret that the absence of duplicate comparative experiments renders these results unworthy of that reliance which we must be able to place on all experiments by which the farmer is likely to be induced to expend his money, or the scientific agriculturist to draw theoretical conclusions. I am glad to learn from Mr Main's paper that he intends to prosecute this point in future years; and I hope he will do it so methodically, and with so much care to eliminate the effect of natural or acquired differences in the soil, that his new results shall prove undoubted accessions to our knowledge.

b Should all the manure be applied at one time?—Many practical men find it better, in preparing their land for turnips,

* The saline matter left when the crude saltpetre of commerce is dissolved and re-crystallised for the use of the powder manufactories.

to plough in the farm-yard manure in the autumn, and to apply any bones or guano they may use, along with the seed, in the spring or early summer. So, with other applications, it is a question of importance to ascertain, not only whether the manure is more profitable when laid on—as is usually done in some districts—only once in the rotation, or when applied two or three several times in as many successive years; but also whether the whole of any top-dressing we may use in any given year should be laid on at once, or should be divided into two or more portions and applied at successive periods. For example, Mr John M'Lintock, of the Harley Works, near Glasgow, made two sets of experiments in 1843 upon different fields of wheat which he top-dressed with saltpetre, in the one case applied altogether on the 17th of April, in the other, one-half on the 17th of April, and the other half on the 6th of May, with the following results per imperial acre:—

	Grain.	Straw.
First, No application, . . .	2689 lb.	3372 lb.
Saltpetre, 84 lb., on 17th April,	2664 lb.	3136 lb.
Difference, . . .	25 lb.	136 lb.

The application in this case may be said to have produced no economical effect.

	Grain.	Straw.
Second, No application, . . .	2552 lb.	3148 lb.
Saltpetre, 28 lb., on 17th April, ... 56 lb., on 6th May,	3068 lb.	4500 lb.
Difference, . . .	516 lb.	1352 lb.*

In this case there was an increase of eight bushels of grain and eleven cwt. of straw. In both experiments the soil was a sandy loam; and in the first field the wheat was sown in November after potatoes; in the second, in December after turnips. But we are unable to determine how much of the apparent increase in the second experiment was due to the application at two successive periods rather than one—*first*, because it is not stated if the weather in May was or was not more favourable to

* *Transactions of the Highland Society*, January 1849, p. 437.

the action of the saline top-dressing than it had been in April; *second*, because the field on which the potatoes had been grown, from this crop being generally manured more liberally, might be much richer in compounds of nitrogen than that on which the turnips had been raised, and might therefore have been less thankful for nitrate of potash at whatever period it was applied; and, *thirdly*, because we have only one experiment in each case, and one undressed portion to compare it with. As I have already remarked, the limits of natural variation being unknown, we can draw no safe conclusion from Mr M'Lintock's results as they have been recorded. They afford encouragement, however, to further trials of this method of applying substances in successive portions.

But Mr Austen, of Chilworth, near Guildford, who farms on the green sand, has informed me, that with common salt alone on his land, he has succeeded in growing an excellent crop of mangel wurtzel, by applying it after the plant was up in successive doses of two cwt. per acre up to six or eight cwt. Every fresh application appeared to give the crop a new start. This result suggests the propriety, at all events, of further investigating the effect of such successive applications.

c At what period of each plant's growth. As to this point, we naturally conclude that any substance which is to benefit a plant, should be brought within reach of its roots, at the time when those parts of the plant are about to be produced to which this substance is especially necessary, or in which it usually abounds. Should we therefore administer ammonia, nitrates, &c., when the plant is young, and phosphates when it is approaching to maturity, or ought all to be mixed and applied at once when the plant is commencing its most vigorous growth? On this point experiments are wanting.

2°. *The manner* or mode of application is not without its influence. It may not only render doubtful the produce of a particular plot, but it may make it impossible to judge of the precise effect of a whole series of experimental trials. For instance:—Mr Main, in 1846, made two series—the one of six and the other of thirteen experiments, upon the same field of oats. In each set was included a plot to which no application

was made; and with the produce of its own undressed plot, the results of each series were compared. But the two undressed portions gave results differing as much as six bushels from each other—a difference which might be due to natural differences in the soil, but which Mr Main thus explains:—

"A stiffish breeze was blowing at the time of the top-dressing; and as the undressed portion was chosen in the vicinity of that top-dressed with Peruvian guano, the dust from this substance was blown upon it. The guano plot was thus injured; and there can be no doubt that, in proportion as it was injured, the undressed portion was benefited."*

If this explanation be correct, then there is no standard with which to compare the other results in the same series of experiments; and being incorrect, the apparent produce of the undressed portion ought not to have been published, as it is only fitted to mislead. If, on the other hand, the difference be caused by natural differences in the soil—and, on a crop of 64 to 70 bushels, a difference of 6 bushels is not very great—there then is no certain standard with which to compare either of the series of results obtained. The several results may be compared among themselves; but they do not enable us to judge of the absolute effect of any of the substances employed.

The mode in which a substance is applied, therefore, should be such as to exclude all causes of doubt; while duplicate or triplicate experiments in every case should enable us to eliminate such causes when they accidentally intervene.

3°. *The form* in which the substance is applied, has also much to do with its apparent success. This has lately become more generally understood, from the economical benefits which have in so many cases followed from the practice of dissolving bones by means of sulphuric and other acids.

It may be laid down as a general rule, that the more minutely any substance is divided, the more immediate and the more sensible will be its effect upon a given soil or plant. The reason of this is, that not only is a substance, when thus divided, more widely and equably diffused over a field, and more generally brought within reach of the roots, but it is also more

* *Transactions of the Highland Society*, Jan. 1848, p. 157.

easily dissolved by the water which is to convey it into the plant—is more readily acted upon directly by the extremities of the roots themselves—and produces more quickly and completely those chemical changes on which its beneficial action, in respect either of the soil or of the plant, always in a great degree depends.

Hence, if one man apply a substance in hard and sparingly soluble lumps, and another in the form of a fine and more soluble powder—if one apply it in a solid and the other in a liquid form—if one apply a concentrated and the other a largely diluted solution—in each case the effects of the same application in the different forms may be different, and results apparently contradictory may therefore be obtained.*

To produce maximum effects we must apply substances in a finely divided state; to produce analogous and properly comparable effects, we must use them under like circumstances and in a similar state.

4°. *The period* at which a crop is reaped or lifted may also influence the result. The effect of many applications being not only to promote but also to prolong the growth of plants, or to cause it go on till a later period of the year, it is obvious that the season or month in which the crop is reaped or gathered must in such cases affect the actual amount of produce. This is especially the case with root-crops, such as turnips, which, under the influence of some manures, may continue to grow as long as the season is sufficiently mild, while, under the stimulus of others, they may attain a more early maturity. Hence, if turnips be lifted in early winter, that a crop of winter-corn may be sown, not only may all the parts of an experimental field yield a less return of this crop than if they had been left longer in the ground, but especially those portions which are still in a state of sensible growth may weigh less than they would otherwise do.

In these modes of treatment, therefore, exists a cause of diversity or discordance in comparative experimental results, which ought not to be lost sight of by the experimenter and the critic.

* For experimental proof of this statement, see my *Elements of Agricultural Chemistry and Geology*, 5th Edition, p. 185.

§ 5.—*Influence of the physical condition of a substance, its state of chemical combination, and its tendency to decompose in a given soil, on the immediate effects it produces.*

1°. *Physical condition.* In the preceding section, I have explained the advantage of extreme mechanical division in exalting the immediate action of fertilising substances. But, even when minutely divided, there are circumstances in which a peculiarity in the physical or molecular condition may modify the apparent action of two different samples of the same substance similarly applied. Thus,

a Gypsum, when burned, parts with its water and becomes friable. It is then easily reduced to a fine powder, and, when applied to the soil, can be easily spread and intimately mixed. But if in the burning it be heated above 300° F. its physical condition is altered; and though it is still easily reduced to powder, it ceases to harden when mixed with water, as common stucco does, and becomes nearly insoluble in water. No experiments have yet been made to ascertain the comparative action of this overburned gypsum upon the land; but if it act sensibly at all, we can scarcely expect it to act so speedily as native or ordinarily burned gypsum is found to do.

b Again,—some varieties of clay are found to be so changed by burning, as greatly to benefit the soil upon which they are laid. But if such clays are *over*burned—heated too long, and to too high a degree—they cease to possess this improving quality, or possess it in a less degree. Like the gypsum, the too great heating has rendered them less soluble than before, and thus less capable of yielding to the soil and plant the ingredients they contain.

Such physical differences may exist in the case of many other substances which may be used for agricultural experiments; and the criticiser of results ought to bear this in mind, as affording a means of explaining discordances among field trials which might otherwise appear inexplicable.

2°. *State of chemical combination.* Suppose two substances we apply—two sulphates, for example—to act solely in consequence of the sulphuric acid they contain, that which was

the more soluble would act the more immediately, the less soluble, after a longer period, and only by the aid of a greater quantity of moisture.

Again,—suppose chloride of potassium and sulphate of potash to act in certain experiments only by the potash they respectively yield—then they may act differently, either because the former salt is more soluble than the latter, or because the plant can extract potash more readily from the one than from the other, or because the one more easily than the other undergoes the necessary decomposition in the soil, before it enters into the plant.

The reader will detect in this statement several interesting points, which can only be cleared up by careful experiments instituted for the purpose. I introduce the matter to his notice among these general considerations, because, in making up recipes containing a mixture of different saline compounds, it has hitherto been usual to substitute one combination of a substance for another—often in consequence of its greater cheapness—a practice which in reality may not be advisable, and may occasion remarkable discordances in the apparent effects of mixtures which on the whole contain nearly the same proportions of those kinds of matter on which plants usually live.*

3°. *Tendency to decompose in a given soil.* This point deserves further illustration. Suppose a potash or soda salt to act only by its alkali, and that this alkali acts in combining with silica and carrying it into the plant: it is clear that before it can act in this way it must undergo an important decomposition in the soil—which decomposition all soils may not be equally fitted to promote. On two soils, differing in this decomposing power, it is clear that the same substances applied in the same way will produce different effects, which a study of the nature of the soils will alone enable us to account for and explain.

It scarcely requires any knowledge of chemistry to understand that a soil rich in vegetable matter—peaty, for example—will act upon a saline substance mixed with it differently

* For a discussion of this topic in another point of view, see page 93.

from one which is poor in organic matter; or that a soil which abounds in lime will decompose compound bodies more energetically than one in which lime is deficient; or that an open soil will admit of, and promote, chemical alterations which a stiff clay will almost or altogether prevent. In these differences, therefore, we have an important source of discordant field results.

I give a special case. Common salt applied alone on certain sandy or loamy soils, in which lime is not deficient, has the recognised effect of brightening and strengthening the straw. To effect this, we at present suppose that it must previously have undergone a decomposition in the soil—forming, probably, first carbonate, and afterwards soluble silicate of soda. To effect this decomposition, however, both the lightness of the soil and the presence of lime may be necessary; and hence on other soils the same beneficial effect may by no means follow from the use of common salt applied alone: mixed with lime its success would be more probable. Used in this state of mixture upon an open soil, the chances of success would be further increased.

§ 6.—*Influence of different varieties of seed in causing discordances in the observed effects of different manures.*

In the raising of turnips, as of almost every other cultivated crop, it is known that the kind of seed employed, independent of all other circumstances, has much influence upon the amount of produce obtained. This is true, especially of what may be regarded as different *sub*-varieties of the plant, of which we are now familiar with so many.

In illustration of this, I quote an experiment made by Mr M'William on the farm of Sheriffston, in Morayshire. He manured three acres uniformly with 13½ loads of farmyard-dung per acre, and 72 lb. of bones dissolved in 46 lb. of sulphuric acid and 400 gallons of water, and sowed on them two sub-varieties of common yellow turnip—Dale's hybrid, of which the seed had been raised on his own farm, and Gibb's red-topped yellow (London seed.) The weights of the crops were, respectively, per imperial acre—

Dale's hybrid,	. . .	20 tons 6 cwt.
Gibb's red-topped yellow,	. .	13 tons 13 cwt.
Difference,	. .	6 tons 13 cwt.

An experiment, therefore, which should simply describe the effect of a certain application on a yellow turnip, without specifying the sub-variety, might be contradicted by the result of another in which a different sub-variety had been experimented upon, and upon which the result had been very different. Even seed of the same sub-variety, grown in different places, often gives different weights of crop.

In regard to wheat, oats, and barley, I might give similar illustrations of the effect of variety or change of seed, but with this almost every practical man is familiar.

It is altogether uncertain, as yet, how far this curious influence of variety, of sub-variety, and even of mere change of seed, will ever be brought within the dominion of chemistry, or admit of being either explained or controlled. Its existence, however, is of much practical importance to the farmer, and ought not to be lightly valued by the scientific experimenter.

§ 7.—*Influence of the seasons on the results of field experiments.*

In turnip husbandry, the influence of a seasonable rain, after the seed is sown, illustrates the kind of advantage which one application, upon which an early rain falls, may have over another which is succeeded by continued drought. Hence the recommendation to apply artificial manures immediately before or after rain, or while moist weather prevails. All field experiments which are to be tested by weight and measure are especially open to this cause of diversity in their results. In the same season the application in more or less propitious weather—and in different seasons the occurrence of more or less rain, or colder winds, or hotter days—will materially modify the results obtained with the same substances upon similar soils and crops.

The variations of heat and cold, and of dryness and moisture, affect especially the gross produce of grass, oats, potatoes, and some other green crops, and the relative proportions of grain and straw in our crops of corn. Thus Mr Lawes observed that in Hertfordshire the proportion of grain to straw in the wheat crop for four successive years, during which different quantities of rain fell, was, upon his experimental fields, nearly as follows. For every thousand of straw, the grain obtained was by weight—*

	Unmanured.		Most highly manured.		Average of all his experiments.
1844, . .	821	...	892	...	968
1845, . .	534	...	569	...	599
1846, . .	797	...	750	...	765
1847, . .	590	...	569	...	580

In 1844, the number of rainy days between May and harvest was only 83; while in 1845 it was 110, or nearly one-half more; and it will be seen from the above table that the proportion of grain to straw, in Mr Lawes' experiments, was inversely as the number of rainy days during the season of growth. It is notorious, also, that in the fens of Lincolnshire and Huntingdon, the year 1844 was a most abundant wheat year—nine quarters being frequent, and, in a few cases, nearly ten quarters being reaped from an imperial acre.†

If the following tabular view of the annual fall of rain on the coast of Sussex—published by Mr Graham, gardener at Bognor, in Sussex, situated in a flat part of the country, ten miles from the Downs, and about 250 yards from the sea—is to be depended upon, it shows how great are the variations in humidity and fall of rain to which our climate, in some counties at least, is subject.

* *Journal of the Royal Agricultural Society*, viii., p. 230.

† Mr Wood, a very clever and intelligent farmer, tenant of Mr Heathcote, of Connington Castle, in Huntingdon, showed me a field, from an acre and 12 perches of which he reaped, on that year, 10 quarters and a bushel; and the whole of the field, he said, was nearly as good as this piece. There has not been such another year since.

	1845. Inches.	1846. Inches.	1847. Inches.	1848. Inches.
January, ...	2·54	3·92	1·73	2·10
February, ...	2·02	1·68	1·85	4·21
March, ...	0·89	2·57	1·04	3·42
April, ...	1·32	2·06	1·04	3·29
May, ...	3·21	1·84	2·10	0·22
June, ...	1·12	1·01	1·34	4·25
July, ...	2·19	1·79	0·77	3·19
August, ...	2·54	4·48	1·37	4·53
September, ...	2·63	3·06	1·32	2·10
October, ...	2·41	6·31	2·37	4·51
November, ...	3·43	2·12	1·57	1·65
December, ...	2·90	1·80	3·88	3·73
	27·20	32·64	20·38	37·20*

The annual fall of rain here ranges from 20 inches, in 1847, to 37 inches in 1848, and the variations in the several months are in nearly equal proportion. Such diversities, whether local or general, must occasion similar differences in the results of experiments made with the same substances, in similar circumstances, in different years; and it is especially to be remarked, that saline applications in very dry years may do harm instead of good—diminishing instead of increasing the crop.

I need scarcely allude to the influence of diversities in the temperature of the air, and of the soil, as necessary sources of dissimilarity among results obtained in circumstances otherwise analogous. The comparative warmth of a season will obviously affect our experiments, not less than its degree of humidity. But, independent of season altogether, as a wet soil is colder than a dry one of the same kind, and as the air on a higher is colder than on a lower elevation, a difference in regard to these circumstances may in the same season cause the same substances to produce unlike effects upon similar crops. The careful sifter of experiments must bear all such things in mind, in comparing results, and in attempting to reconcile such as differ, or to extract general rules and principles from such as agree.

The maker of experiments, also, must neither be surprised nor discouraged if a series of trials which has cost him thought,

* *Gardeners' Chronicle*, March 31, 1849, p. 198.

trouble, and expense, should, by the chances of an unusual season, by the unsuspected condition of his land, or by other accidents, be rendered wholly abortive. Such accidents form one of those numerous sources of delay to which the progress of scientific agriculture is peculiarly liable, which have made its advance so slow, many of its steps in advance so doubtful and insecure, and have disheartened and driven from its service many useful and talented men.*

§ 8.—*When experiments are to be rejected. Value of contradictory and of positive and negative results.*

From what has already been said, the reader will be satisfied, I think, that field experiments are not to be confided in, where the limits of natural variation in the land itself have not been previously ascertained by duplicate or triplicate experiments on the soil without addition, or where, this having been done, only one comparative experiment has been made with the substance, the action of which it is intended to investigate. There are other reasons, also, as the reader must have seen, which will lead him at once to conclude, that entire series of experiments are to be rejected as suspicious—as unfit, therefore, to be trusted to, to find a place in our books, or to be allowed any weight in our reasonings. This subject is, I think, deserving of special illustration.

A series of experiments, published or unpublished, ought, as it appears to me, to be rejected—

1°. *When their results fall within the limits of natural variation.* We have seen that two portions of the same field may give a produce of corn, hay, or turnips, under the same circumstances, differing from each other. In the case of

a Turnips, as much as 25 per cent. Differences which do not exceed 5 or 10 per cent, therefore, may be considered as natural differences; and without further experiments upon the point, conclusions can scarcely be drawn with safety from comparative results which approach each other so closely as this 5 or 10 per cent.

* For an instance of such accidents, see *Transactions of the Highland Society* for March 1849, pp. 500, 501.

b Corn, as much as 5 or 6 bushels sometimes, or more generally 5 per cent may be regarded as a natural difference. Results not differing more than 5 per cent may, in the absence of other proof, be regarded as identical.

c Hay, as much as 10 per cent, in the absence of satisfactory experiment, can scarcely be considered as too wide a limit for the natural differences in this crop.

Now, suppose the results of a series of *single* comparative field experiments to be laid before us, and that on inspecting them we find that, in comparison with that portion to which nothing has been applied, the produce of the other differs in excess or defect no more than 5 or 10 per cent according to the crop; then, in regard to that series of experiments, we ought to decide that no safe conclusions can be drawn from it, as to the absolute effect of this or that substance in the given circumstances. There may be a probability that some of the substances employed have produced an effect, but that probability ought to lead us not to form or adopt an opinion, but to make new experiments on the subject.

If the differences exceed this natural limit of variation, then a positive conclusion to the extent of that excess may be drawn from the comparative results.

From published experiments I might select many illustrations of this position. I shall confine myself to two taken from a table of the results of twenty-three experiments upon turnips, by Mr Lawes, made in 1843.*

a In these trials, the portion to which no manure was applied, yielded 4 tons 3 cwt. of bulbs, which only weighed half-a-pound each on an average. In all the twenty-two other experiments, the produce of bulbs varied from 8 to 12½ tons, and the bulbs weighed each on an average upwards of a pound. The conclusion, therefore, in this case is a safe one, though the experiments be only single, that every one of the substances employed did, under the circumstances, possess a large fertilising power. But

b Of the twenty-three results reported in this table, ten vary between 10 and 11 tons of bulbs per acre. Differing not

* *Journal of the Royal Agricultural Society*, viii., p. 503.

more than 1 ton, or 10 per cent, they ought, in the absence of test experiments, to be considered as practically identical. In an economical point of view, none of the substances applied in these ten experiments can safely be concluded to be more fertilising under the circumstances than the others.

2°. *When among the results there are one or more of a suspicious nature*, if they are not altogether rejected, our judgment regarding them ought at least to be suspended. Thus—

a In the same table of experiments on turnips made by Mr Lawes in 1843, it is stated that,—

No manure gave, ...	4 tons 3 cwt.	of bulbs.
6½ cwt. rape-cake, ...	8 ... 4	...
5¼ cwt. rape-cake, and 2 bushels of yeast,	8 ... 1	...
8 bushels of yeast, ...	10 ... 19	...

Here the rape-cake alone gave a much less increase than the yeast alone; yet the substitution of one-fourth of the quantity of yeast for one-sixth of the quantity of rape-cake, gave a less return even than the rape-cake alone. This is by no means impossible, but it is unlikely. And that such facts as this would be really interesting, if proved, increases our regret that experiments are not so multiplied—done in duplicate or triplicate—as fully to test them.

b Again, in a detail of experiments made upon yellow turnips, in 1843, by Mr John Wilson, of Eastfield, Penicuick, the three following are placed at the head of the list:—

No manure, produced in bulbs, .	2 tons 16 cwt.
Farm-yard manure, 11 yards, . .	3 ... 15 ...
... ... 22 yards . .	18 ... 13 ... *

That 11 yards of manure should only add 19 cwt. to the crop, while 22 yards added nearly 16 tons, appears to me a very suspicious result. It certainly implies, at the least, some peculiarity of circumstances to which the experimenter ought to have adverted and endeavoured to explain.

3°. *Or when the results are inconsistent with each other.* Thus—

* *Transactions of the Highland Society*, January 1849, p. 442.

a The same Mr Wilson, in the same series of results, states that,—

358 lb. of guano per acre gave	.	17 tons 3 cwt., and
538 lb.	. .	16 ... 6½ ...

where one-half more guano gave 16½ cwt. less produce, the manurings in neither case being extreme.

b Mr Main, at Whitehill, in 1847, used dissolved bones, mixed with wood ashes, prepared night-soil, sugar refuse, and nitrate of soda, in raising green-top globe turnips. He applied the mixture in three different proportions, with the following results per imperial acre :—

	Bulbs.	Tops.
1°. With 1932 lb. per acre, the produce was	22 tons.	6⅛ tons.
... 1732	19½ ...	5½ ...
... 1532	21½ ...	6⅛ ...

Here the smallest quantity gave nearly as much as the largest, while the middle proportion gave less both of bulbs and of tops. It is unfortunate, also, that these three results form a part of a series of eight experiments, the results of which are tabulated,* and must have cost Mr Main much time and expense. But for want of duplicate or triplicate experiments, and the knowledge of the limits of natural error which such experiments alone can give us, these, like many other carefully conducted series of experiments already made and published, fail to lead to any useful and trustworthy result.

c On the farm of South St Colmar, in Bute, in 1847, it is stated that

6 cwt.	of guano gave	30 tons	15 cwt.	of turnips.
5 ...	... ...	31 ...	17 ...	...
4 ...	... ...	32 ...	0 ...	...

the produce, as in Mr Wilson's case, increasing as the manure diminished.

d On the Kerrytonlia farm, in the same island, in 1847,

24 carts of yard dung, with 16 bushels of bones, gave	27 tons 7 cwt.
24 ... ... 14	29 ... 7 ...
Being a difference of	2 tons.

* *Transactions of the Highland Society*, March 1849, p. 540.

e And on the same farm, in the same year,

24 carts of dung, and 2½ cwt. of guano, gave	28 tons	7 cwt.
24 ... ... 3	25 ...	4 ...
Being a difference of	3 tons	3 cwt.

Such sets of experiments as these three last are mere rubbish, and I quote them here as illustrations of the kind of results which ought not to be given to the public. To the individual who made them they may be useful in showing that his methods of experimenting are in error somewhere, in leading him to the cause of his contradictory results, and in preparing him for making trustworthy experiments hereafter; but the public ought to have been spared the infliction of studying them.*

The last two experiments made at Kerrytonlia might have been adduced as illustrations of the extent to which farm-yard manure may differ in fertilising virtue—a fact to which I have adverted in a previous section. But such an illustration would have been open to the objection, that we have no experimental proof that the different parts of the field might not alone, and without manure, have given returns widely differing from each other.

We have, in fact, three elements or unknown quantities involved in these experiments—the soil, the farm manure, and the guano, and only one pair of experimental results from which to deduce the action of each of the three. It is impossible to say how much of the difference observed is due to each. Such experiments, therefore, only uselessly load our books, and give additional labour to those who wish to extract, from the results of practical men, experimental data by which to guide their researches, and test the opinions they may form. I may here remark that, in all experimental inquiries, it is of the greatest possible consequence to eliminate every conflicting cause—to remove every circumstance which may interfere with the determination of the precise point which we wish to ascertain. This is very difficult, and, as a general rule, will require at least two

* See also chapter x. § 4.

experiments to bring out the exact influence of each new cause of diversity.

I have before me numerous sets of experimental results, carefully tabulated and published by the experimenters. Each experiment, in general, differs from the others, and the entire differences among the field-results are usually ascribed to the differences among the applications—to the variation in quantity or in quality of the substances laid on the land.

But it is forgotten, not only that two repetitions at least of each experiment ought to be made, but that the action of substances, when mixed or applied together, is different from their action when applied singly. They exalt or lessen the action of one another, and thus there may be no real or direct relation between the increase of crop and the quantity of any new substance contained in the mixture laid on. Thus, common salt produces a certain action upon the potato and oat crops under certain circumstances, and nitrate of soda produces a certain different action; but a mixture of the two, one-half of each, produces a result in general much more favourable than the average of their actions when applied singly. Thus it is not to the nitrate of soda added that the increase of crop is to be ascribed above that which salt alone gives, but to the special action of the two taken together as a mixed application.

It is thus clear that, to arrive at theoretical truth in regard to the precise virtue we should ascribe to any two fertilising substances, we must have at least two experiments with each taken singly, and two with the mixture which contains them. From the differences thus obtained, we may be able to draw conclusions as to the influence which each exercises in the given circumstances, either when applied alone or when mixed with the other substance.

4°. *When the results obtained in the same circumstances are obviously contradictory among themselves*—like some of those from the island of Bute above quoted. A careful examination of published tables of experiments will show many such contradictions.

And yet contradictory results, obtained at different times, by

different persons and in different places, are not to be rejected. We are not to set a good result against a bad one, and to allow them, in our minds, to neutralise each other, and thus reject them both. We ought rather, if the experiments have been made with equal care, to receive both as expressions of the truth under the circumstances in which each has been obtained. Where the differences are remarkable, we ought to inquire what the special circumstances have been from which differences so large can have arisen.

In this branch of experimental inquiry, we cannot, as I have said, set a positive against a negative result, or *vice versa*. In the positive, so much truth may be actually and visibly gained; but in the negative, we may have a no less valuable indication of the existence of circumstances by which the ordinary effect of a given substance may be wholly prevented. The search after these circumstances may lead us to truths no less important than those which may appear to flow from the positive result; and thus, in the words of Bacon, "though what succeeds may please more, what succeeds not may inform no less."

I need not add, what every practical man will say to himself, that any experimental result which is inconsistent with general experience must be very cautiously received, and submitted to searching criticism and careful repetition.

§ 9.—*Is it desirable that experiments in practical and scientific agriculture should be extensively made?*

This question may be considered in several aspects.

1°. *Is it desirable for the state?* Everything which is likely to increase the gross agricultural produce of a country, if not too costly, must be desirable for the state. The permanent wealth and power of a great country depend upon the produce of its soil, and the one must increase with the other.

"It may with certainty be stated," says Lampadius, "that by the use of gypsum, the produce of clover, and the consequent amount of live stock, have been increased in Germany *at least one-third*."* This illustration is sufficient to prove the importance of agricultural experiment to the national welfare.

* *Die lehre von den Mineralischen Düngmitteln*, p. 34.

There are many applications which are fitted to produce, in most countries, effects quite equal to those produced by gypsum, and it is desirable that, by numerous trials, the value and influence of such substances, in each locality, should be established and made widely known.

2°. *Is it desirable for the science itself?* I have already stated that, according to my views, the progress of scientific agriculture is to be greatly promoted by the introduction of a more general, and at the same time a more cautious and more exact system of rural experimenting throughout the whole country. Important practical facts will be brought out, opinions will be tested, received theories corrected, and the suggestions of hypothesis put to the trial. The science will also be advanced by the greater interest it will awaken, and the more numerous cultivators it will attract. The general esteem for a study, and the degree of attention bestowed upon those who prosecute it, are always important elements in securing for it a larger amount of talent and energy, and a more rapid advance.

3°. *But is it desirable for the farmer?* Intellectually considered, we have already seen that it is highly so, as it will impart a new interest to the ordinary routine of his farming operations; and by calling forth thought, and leading to inquiry and discussion, will gradually elevate the class to which he belongs.

But, as a matter of profit, such experiments are deserving the attention of the rent-paying farmer. They cannot be a source of loss, because rightly (that is prudently) conducted, experiments will always, on the whole, more than repay the expense of making them; and no prudent man ought to begin his experiments on such a scale that he would suffer any material injury were they to fail altogether.

I may instance some of the results obtained by Mr Fleming of Barochan, as showing how much crops may be increased, at a cheap rate, by the careful experimenter.

Thus, three successive crops of potatoes, oats, and hay, in 1842, '43, and '44, on two parts of a field, treated the one with farm-yard manure alone, the other with farm-yard manure mixed with other substances, gave the following economical results:—

Manure applied.	Produce reaped.	
1°. Farm-yard manure alone, 30 tons,	Potatoes,	9 tons 3 cwt.
... ...	Oats,	61 bushels.
.. ..	Straw,	1 ton 16 cwt.
... ...	Hay,	2 tons 5 cwt.

Cost of Manure, £10, 10s.; Value of produce, £36, 12s.

2°. Farm-yard manure, 14 tons, .	Potatoes,	15 tons 1 cwt.
Peruvian guano, 3 cwt., . .	Oats,	70 bushels.
Sulphate of magnesia, ½ cwt., .	Straw,	2 tons 7 cwt.
Gypsum, 1 cwt., . . .	Hay,	2 tons 5 cwt.

Cost of manure, £6, 18s. 6d.; Value of produce, £50, 6s.*

Balance in favour of the mixed manures, £17, 5s. 6d., or £5, 15s. an acre every year.

Again, two successive crops of potatoes and barley, treated in three different ways in 1843 and 1844, gave the following results:—

1°. *Manures applied* per imperial acre—

	a	*b*	*c*
	Farm-yard manure, 30 tons.	Farm-yard manure, 14 tons. Peruvian guano, 3 cwt.	Farm-yard manure, 14 tons. Peruvian guano, 3 cwt. Sulphate of magnesia, ½ cwt. Gypsum, 1 cwt.
Cost of manures,	£10, 10s.	£6, 12s.	£6, 18s. 6d.

2°. *Produce reaped* per imperial acre—

	a	*b*	*c*
Potatoes, .	14 tons.	16 tons.	18 tons.
Barley, .	63 bushels.	68½ bushels.	66 bushels.
Straw, .	48½ cwt.	45½ cwt.	43 cwt.
Value of produce,	£42, 13s.	£47, 7s.	£51, 5s.†
Balance in favour of mixed manures,		£8, 12s.	£12, 3s. 6d.

or four and six pounds an acre respectively.

* Potatoes reckoned at 40s. a ton, oats 2s. 6d. a bushel, straw 2s. a cwt., hay £3 a ton.

† Potatoes reckoned at 40s. a ton, barley at 3s. 6d. a bushel, and straw at 1s. 6d. a cwt.

It must be the interest of every rent-paying farmer to make his farm-yard manure go farther, and to aid its action by admixtures such as those above described, the results of which were so profitable to Mr Fleming. If so, it must also be his interest to make experimental trials, by which the admixtures best suited to the soil he cultivates, the crops he grows, and the yard-manure he prepares or manufactures, are alone to be discovered.

In regard to experimental top-dressings upon young crops, in addition to ordinary manure, the testimony of a practical farmer who has made many experiments, (Mr Alexander J. Main, of Whitehill, Mid-Lothian,) is also deserving of the attention of my readers. "Looking at the results of experiment," he says, "I am entitled to conclude that, on the whole, the larger the outlay on a top-dressing, judiciously managed, the greater and more profitable the results."* It is not impossible, therefore, to unite the immediate profit, which the farmer has a right to look for, with the more generally useful experimental inquiries which the scientific agriculturist desires to undertake.

* *Transactions of the Highland Society,* March 1849, p. 495.

PART II.

EXPERIMENTS WITH SALINE SUBSTANCES, APPLIED ALONE AND WITH LIME, CLAY, AND OTHER MINERAL SUBSTANCES.

CHAPTER V.

Wide range of agricultural experiment. Arrangement and subjects of the suggestions contained in the present work. Experiments with saline substances applied alone. General objects or aims of field experiments. Practical and theoretical purposes for which experiments with single substances are made. What is a successful experiment? Can mineral or saline substances applied alone be depended upon as manures for our cultivated crops on the generality of soils? Circumstances in which saline or mineral applications are likely to produce the most sensible effects. General suggestions for experiments on this subject. Equivalent quantities of the different saline substances used in comparative field experiments. Circumstances which ought to be stated in regard to all soils and localities selected for experiment on publishing the results of trials made upon them.

THE range of experiments in practical agriculture is exceedingly wide, and the questions to be solved by them are varied and complicated almost without end. For the sake of clearness, I shall arrange the suggestions I intend to offer under the following general heads:—

I. Experiments with saline substances applied alone, and with lime, clay, and other mineral substances.

II. Experiments with natural and artificial admixtures of saline substances.

III. Experiments with natural manures, vegetable and animal.

IV. Experiments with waste substances of various kinds, and with the refuse of manufactories.

V. Experiments on seeds, cultivated crops, and trees.

VI. Experiments on the destruction of insects, weeds, and parasites.

VII. Experiments in manuring and improving the soil, and in reference to the suggestions which may be derived from chemical analysis.

VIII. Suggestions regarding the manufacture of artificial manures, and the mode of testing their value by experiment.

IX. Experiments on the general treatment and feeding of animals.

X. Experiments on dairy husbandry, on the making of cheese and butter, and on the management of wool.

XI. Experiments on theoretical chemistry and physiology in their application to agriculture.

In the present state of scientific agriculture, and especially considering the unsettled position it still occupies in public opinion, such theoretical researches only ought to be undertaken as have an immediate and obvious practical bearing upon rural economy. There are, at this moment, abundance of such inquiries to occupy the full attention of all our agricultural chemists for many years to come. To these I shall draw attention from time to time, but in this last part of my observations they will come prominently forward.

The consideration of the several departments of practical and scientific agriculture above enumerated, will lead me over nearly all the debateable ground of this department of applied science; and, while it will show how very much remains to be done, will also, I hope, stimulate not a few persons to lend their aid in completely subduing and colonising it.

§ 1.—*General objects or aims of field experiments.*

The aim or object of the field experimenter is different according as his views are altogether practical, or combine theoretical with practical investigation. The practical man inquires into such points as these,—

1°. How far the natural soil of his farm may be improved by this or that process, or by this or that application.

2°. How his crops may be increased in quantity, improved in quality, or protected from this or that insect, or from this or that form of blight.

3°. How this or that kind of waste upon his farm may be prevented, and the natural fertility of his land be thus economised.

4°. How this or that refuse substance of the farm or the manufactory may be applied to an economical use.

5°. How the manures at his command may be made to go farthest, or produce the greatest economical effect.

6°. What single or mixed manure ought to be given to a particular crop on his particular soil.

7°. What special additions the manure made on his farm requires, to fit it for this or that particular crop, owing to the way it is prepared, to the kind of husbandry practised, the kind of produce sold off, and so on.

8°. When and in what state the different manures he has at his command may be applied most economically on his soil, in his climate, and for the crops he especially wishes to grow.

9°. Ought the manure to be given to the land all at once, or at two or more several times during the season or the rotation?

10°. If not all at once, ought all the ingredients of a mixed manure to be given together in a state of mixture—part of the mixture at one time and part at another?—or ought some of the ingredients to be applied singly at one season (the spring or autumn) or at one period of the rotation and some at another, on his soil and for his crop?

11°. Ought some, for example, to be given when the plant is young, others when it has grown to a certain height, and others again when it approaches maturity—to produce the greatest apparent effect or actual profit?

12°. How the produce of his farm may be most economically made use of, in rearing, feeding, and fattening cattle, or in producing milk, butter, and cheese—how the quality of these dairy products may be improved—how they are best preserved, and so on.

Such inquiries as these the practical man makes; and, by

field and house experiments, he will aim to solve them in reference to the special circumstances in which he lives, and with a view to his own especial money profit. It is a part of his profession to make such experiments; but, at the same time, both to devise and to conduct them so prudently, and on such a scale, that they can never, should they fail, be productive of any loss which he will seriously feel.

The theoretical experimenter, again, has other objects, which he pursues either alone or conjointly with those which the purely practical man keeps before him. He tests theoretical views and hypotheses; tries the value of the deductions and inferences to which the results of analysis seem to lead; investigates questions in practical physiology; inquires into the kind and mode of vegetable nutrition; the relation of manuring substances in composition, form, and chemical or molecular constitution, to the composition and state of the soil, to their action on this or that plant, at this or that period of its growth; the necessity of this or that substance, in this or that form, to the growth of particular plants in this or that soil or climate; the influence of one substance in modifying the action of another upon a given plant; of different substances in modifying the composition of the plant produced by their assistance, and its consequent greater or less value for food and other purposes.

Such as these are the additional questions which the theoretical experimenter seeks to solve by the trials he makes in the field. They are not inconsistent with the questions asked of nature by the practical man. Though higher in aim and character, they may be conjoined with his; and though they demand knowledge—wider in its range, and more precise in character—and involve a greater attention to strict accuracy in the execution, yet in neither respect are they beyond the powers or means of the instructed agriculturist. It is an inducement to the latter also to take up such higher questions, that, by the charm and interest which attaches to them, they give to rural life a new character, imparting to it a portion of that intellectual exercise and excitement for which men usually repair to towns, and the want of which is not unreasonably supposed to retard the diffusion of useful knowledge in all purely agricultural districts.

§ 2.—*Practical and theoretical purposes for which experiments with single substances are made.*

Experiments with *single* saline or mineral substances are made with the view of ascertaining—

1°. If they are required by, or can be profitably applied to a particular crop, on a given soil, when treated in a given way. For example—

a When, during the making of the manure on a farm, the ammoniacal matter is allowed to run to waste, either in the form of liquid manure or of gaseous ammonia—will land, dressed with such manure, be grateful for, and give a profit upon, the application of salts of ammonia, or other salts containing nitrogen, the most valuable constituent of ammonia?

b When, by the growth and sale of corn crops, by the export of cheese, or the rearing of young stock, the land has been, or is presumed to be, exhausted of phosphates—will it be specially advantageous to apply preparations containing phosphoric acid? —and so on.

2°. The abstract general effect of a given elementary or other substance upon vegetable growth.

3°. The abstract special effect, if any, which it exercises upon this or that particular crop.

4°. The influence of known circumstances in modifying this general or special effect.

5°. How far the state of chemical combination, in which a substance is applied, interferes with or changes its general or special effects. Whether these several compounds perform the part of distinct agents with peculiar actions upon plants, distinct from those of their constituents—or whether their action is compounded of the joint influences of the substances of which they consist?

The first of the objects above stated is altogether practical; the others are theoretical or scientific in the first instance. All such inquiries, however, are sure to lead, either directly or indirectly, to important practical and economical deductions.

How the several classes of experiments are to be made will be explained hereafter.

§ 3.—*What is a successful experiment?*

In pronouncing whether an experiment has been successful or not, it is necessary to have a clear idea of the purpose for which it has been made, and of its fitness to attain that purpose under the circumstances in which it is tried.

Generally, however, an experimental application may be said to be successful, either economically or theoretically—

1°. When it causes the production of a decidedly larger crop than would have been raised without its assistance in the existing circumstances.

2°. When the crop, after paying the additional cost of the application, leaves a larger profit than it would otherwise have done.

3°. When it illustrates the mode of action of the substance applied upon a given crop, in given circumstances—or throws light upon some obscure point, in theory or practice.

4°. In this sense it may often be considered successful when, after repeated trials, it is found to produce no sensible effect whatever. A decidedly negative result may often be as useful as a positive one, not only by preventing the outlay of money on the part of the practical man, but by clearly proving or disproving some theoretical question.

5°. When it suggests new, further, and perhaps more interesting experimental researches.

In this last case, an experiment may prove of great value to the theory of agriculture, and may ultimately be productive of great benefits to the progress of knowledge. Indeed, all new steps in knowledge are suggestive of further research; and it is one of the most valuable consequences of beginning to experiment, with however little knowledge of the subject at first, that a thinking and reading man comes by degrees not only to see his way clearly through what he is actually doing, but to ask new questions of himself, which new experiments, probably never before thought of by any one, can alone enable him to answer. Almost every result he obtains suggests to him further inquiries, when its true meaning is perceived or suspected; and thus not only is a habit of strict investigation

acquired, but the spirit and love of it are awakened and encouraged in his mind.

§ 4.—*Can mineral or saline substances, applied alone, be depended upon as manures for our cultivated crops, on the generality of soils?*

This question has been forced upon the attention of practical men during the last two or three years, in consequence of the broad assertions made by some writers upon the subject, whose knowledge of practice was not sufficient to enable them to take into consideration all the points which the question involves. It has also become an important economical question, because of the vaunted universal virtues of many so-called *inorganic* or purely mineral and saline manures which are now offered for sale, and the purchase of which has been a cause of frequent loss to the rent-paying farmer, on whose land and crops they were by no means suited to produce a profitable effect.

There are two facts which I think will guide us to a safe general answer to the question, Whether mineral manures alone are to be depended upon as fertilising substances?

1°. All fertile soils, in every part of the world and in every climate, are found to contain a notable quantity of organic matter, either animal or vegetable. And although the fertility does not depend upon, and is not proportional, therefore, to the *quantity* of this organic matter,—as is seen in the case of peaty soils,—but rather upon the chemical state in which the organic matter exists, yet it appears certain, as the result of universal experience, that animal or vegetable matter must be contained in sensible proportion in every soil from which good crops are to be reaped without any further addition.

2°. Plants, as we have seen, consist of an organic and a mineral part, and live partly on organic and partly on mineral food. Of this organic food, they draw a portion directly from the soil. Chemical physiology, therefore, confirms the results of experience, that, to produce good crops, a soil ought to contain a proper quantity of available organic matter.

Now from these two facts it clearly follows, that a manure, whether natural or artificial, which shall, in all circumstances

and in every soil, cause good crops to grow, must, in addition to mineral or saline, contain also some animal or vegetable substances, or, in their stead, some ingredients of organic origin, which chemistry may point out as likely to supply the place, by performing the natural functions of animal and vegetable matter.

This general result is by no means inconsistent with the good effects which are, I believe, truly enough stated to have, in numerous cases, followed from the unassisted application of purely mineral as well as of purely organic substances or mixtures, to certain soils and crops. But the circumstance of such results being *possible*, only shows more clearly the money value to the practical man of that kind of knowledge which is likely to enable him to distinguish where and when they can respectively be expected to succeed, and in what circumstances the chance of failure and of consequent loss predominates.

Some of these circumstances, as regards purely mineral manures, are stated, or may be inferred from what is contained in the following section.

§ 5.— *Circumstances in which saline or mineral applications are likely to produce the most sensible effects.*

1°. Saline substances act most immediately and most efficiently when they are in an exceedingly minute state of division, and when the land and crops to which they are applied are already moist, or when rain falls soon after the application.

2°. Generally they produce most effect upon soils which contain the least of the several ingredients of which the saline substances themselves may consist.

This general rule, however, involves and may be subdivided into several special rules or cases. Thus,—

a It is the result of observation that saline applications of certain kinds, whether single or mixed, produce the most marked effects on comparatively poor soils. Those which are naturally rich, in the ordinary sense of the term, are less likely to exhibit striking differences when a top-dressing of a saline substance is applied to them, because the quantity of the substance laid on, compared with the weight of the same substance already present

in such a soil is usually much less than in the case of one that is naturally poor. That a substance produces no sensible effect upon a given soil is therefore no satisfactory proof that it is not propitious to the plant we are growing. It may be that the special circumstances in which we apply it are not fitted to display or to allow of the development of its peculiar action.

b It is also the result of observation that, in some districts and on some soils, the natural or artificial application of mineral matter alone is productive of most profitable results. Thus, in the neighbourhood of Vesuvius, according to Mohl,* the permanent richness of the soil is owing in part to the ashes sprinkled over its surface from the mouth of the volcano, which ashes destroy the growing crop on an average every eighth year. So, also, the artificial application of inorganic or mineral manures to certain soils in our own country have, without other addition, produced largely increased crops. But these good effects are in every instance dependent upon the natural presence in the soil of a sufficient supply of those organic forms of food required by the plant, and which are not contained in the mineral substance or mixture applied to the land.

From a consideration of such facts we obtain a key to the circumstances or conditions under which mineral manures may be tried, alone or by themselves, not only with profit, but with positive benefit to the land, as well as an explanation of certain methods of treating the soil, which in practice have, in some localities, been found advantageous. Thus,—

First, If the land is rich, and in good heart, as it is called, saline or mineral manures, without any admixture of nitrogenous matter, may be applied with a fair prospect of advantage.

* Dr Justus Liebig's *Verthältmiss zur Pflanzenphysiologie, von* Dr Hugo Mohl, 1843, p. 47.

In the passage referred to, Mohl is combating the statement of Liebig that the fertile soil in the neighbourhood of Vesuvius contains no organic matter, and is therefore permanently fertile solely because of the mineral top-dressings it receives from the volcano. But this soil is only sparingly sprinkled with ashes even when the fall is sufficient to destroy the whole vegetation; and, as Mohl observes, this very destruction is the means of applying a rich green manuring to the soil, by which the proportion of organic matter contained in it is kept up or increased.

Second, When the land, in consequence of the excess of organic matter of a particular kind, causes the grain to tiller much, and to fall or lodge, the use of unaided mineral manures is indicated.

In practice, this tendency to straw is counteracted by taking two or more corn crops in succession to *bring it down*—by raising turnips with peat ashes alone, where these are easily obtained—by growing potatoes with wood ashes or with artificial admixtures of saline substances—or by paring and burning preparatory to any crop. It is obvious that both skill and judgment are required in determining when and how often any of these practices ought to be resorted to, with a view not only to the benefit of the crop which is immediately to follow, but also to the future good of the land; for though it may be clear that one or other of these forms of treatment is the most advisable for a given time, it is quite certain that a continuance of such procedure will by-and-by—that is, in proportion as the organic matter becomes exhausted—both diminish the crops and injure the land.

c I merely mention, as a third result of observation, that, on many soils, organic matter alone—or, generally, substances rich in nitrogen applied alone—succeed well, and, without any admixture of mineral matter, add largely to the crops the land is made to produce. The reason of this is, in most cases, exactly the converse of that to which I last adverted. The soil being more or less rich in mineral and poor in organic matter of the proper kind, is most grateful for an addition of the latter, and for a time returns large profits upon every application of it.

§ 6.—*Why saline substances are not always useful in inverse proportion to the quantity of them contained in the soil?*

But the general rule above stated, (2°,) that a substance is productive of benefit when applied to the land in inverse proportion to the quantity of the same substance already existing in the land, is susceptible of modifications of much importance, and which must be kept constantly in mind if we are to be able to explain the many appearances which, in ordinary farming, and especially in the kind of field experimenting we are now

considering, are likely to come under our notice. I merely enumerate four more or less obvious causes of such modification.

First, Though the substance we add—it may be potash or soda, for example, or a substance containing nitrogen—may be present in the soil to which we add it, yet it may not be in such a state of combination or of solubility as readily to minister to the wants of the crop that is growing upon it. The application we make, therefore, may produce a much more striking effect than its quantity, compared with what is already present in the surface soil, would warrant us to expect—and this because of the chemical or physical condition in which we apply it being such as to make it more immediately available to the nourishment of the plant.

Second, The converse may also be true. A large quantity of a substance laid on the land in one physical condition, may produce a less sensible effect than a smaller quantity applied, or already existing, in the land in another physical condition. Such we know to be the case with bones, which, when reduced by means of sulphuric acid, produce a more immediate and much more striking effect, than when used in the state of ordinary bone-dust.

The state of chemical combination in which it exists also modifies the special action of a substance. Such is the case with quicklime, compared with common marl or chalk, and such also is the case with the various states of combination in which magnesia, potash, soda, ammonia, and the nitric, sulphuric, and phosphoric acids, may be presented to the roots of plants through the medium of the soil.

It is obvious, therefore, that the physical condition, and the state of chemical combination, in which we apply a given substance to our fields, will materially modify the effect it would be expected to produce if we attended only to the relative quantities in which it exists in the soil, and in the application we make to it.

Third, This question of the influence of chemical combination is deserving of further and more profound investigation. We have seen that substances must be soluble if they are directly to promote vegetable growth. But will a nutritive substance,

organic or mineral, in any state of chemical combination, if equally soluble, be equally acceptable to a given plant, and equally promote its growth? So far as our knowledge goes, it inclines us to answer—no. Of two equally soluble states of chemical combination of the same acid or base, the one may produce, all other circumstances being the same, a more sensible effect than the other. Whether this difference is to be ascribed to the special influence of the second substance with which the acid or base is combined, or to the special properties of the compound body as a compound, are interesting theoretical points which, by repeated field experiments, we are anxious to determine.

But suppose these questions settled, another equally interesting follows. If a plant A is most grateful for a substance in a given form of combination, will another plant B be also most grateful for it in the same form? Will wheat and oats be equally benefited by ammonia, or sulphuric acid, or phosphoric acid, or lime, in the same state of chemical combination? Will the bean and the turnip prefer also to have them in the same form as the kinds of grain we have mentioned? These are interesting but very deep questions, which only long and careful experimenting can solve.

But inasmuch as every plant contains and produces some forms of matter (chemical combinations) peculiar to itself, it is not unlikely that certain combinations of a given substance, special for each plant—for each variety, species, or genus—may favour its growth more than others will do. Can we even hope to arrive at such refined knowledge as this? But if we ever do, how rich in direct practical applications will it be to the art of tending and feeding our crops, of doctoring and economically manuring our soils?

Sulphur exists in one peculiar state in our onion and garlic crops, in another in our corn and common root-crops. The potato and the parsnip produce starch, the carrot and the turnip pectic acid; wheat produces gluten, the pea and the bean legumin, and Indian corn and the oat substances differing from both. Are certain chemical forms of any given saline food better adapted than other forms to the production of these

several substances in the plants in which they are found? At present we feed them all with the same kind of food in the same form—ought we to vary the form of combination with the kind of plant, so as to arrive at the most certain and most profitable result? Will less of the same substance produce an equal effect in the case of each plant, according as we apply it in this state of combination or in that?

Again, the necessity of nitrogen to the growth of all our plants is now universally acknowledged, and it is believed that in many instances ammonia is one of the forms in which it is most beneficially and most profitably applied. But according to Persoz,* the application of the smallest quantity of a solution of acetate, sulphate, or carbonate of ammonia, or of sal-ammoniac, destroys in a short time the common pansy, (*viola tricolor*,) and a plant of *cobea scandens* was in his experiments speedily killed by a solution of acetate of ammonia.

Are we to conclude from these experiments that ammonia is unsuited to these plants, and that their nitrogen must be administered and taken in in another form? or was it the state of combination in which the ammonia was presented to the plants that caused the injury? In what state, in short, is nitrogen best adapted to each plant we grow? and if ammonia be a suitable form for all, in what state of combination, and how and when should we add it to each?

We might put similar queries in regard to every substance, organic or inorganic, which the perfect plant contains. But I must not here dwell on these questions. The reader will not fail to see, however, that the answer to them may introduce very important modifications into the general rule (2°) in regard to the effect of saline applications, which I ventured to set down at the commencement of the present section.

Fourth, The fourth cause of modification of our rule requires no illustration. We have already seen that plants require eight or ten mineral substances to build up their several parts. If the soil be defective in a number of these, and the saline or mineral application we make supplies only one of them, it is

* *Annalen der Chemie und Pharmacie*, lxv., p. 129.

quite clear that no important benefit can be produced by it. Its effect in this case will be determined neither by the quantity of the substance we apply, nor by the quantity of it already contained in the soil, but by the absence of other substances which are necessary to its usual and legitimate action—as mortar is necessary to the builder, to render available the bricks and stones already at his disposal.

§ 7.—*General suggestions for experiments on the most profitable time of applying different saline and other substances when employed alone.*

I have already drawn the attention of my reader to the influence which the application of a substance at one period of a plant's growth, or at one period of the year, may have upon its sensible effect in promoting or retarding vegetation.

Chemical physiology and agricultural experience, so far as they have gone, appear to indicate that in our climate—

1°. There is, in regard to many of those substances which we do or may profitably apply to our crops, a certain period of the year, or of the plant's growth, at which, other things being favourable, each substance may be most advantageously and economically applied to each crop on each soil.

2°. That smaller applications of a given substance at successive periods of growth *may* be more profitable than one larger application made at once.

But we have as yet little certainty in reference to these points; and I may say no accurate experimental results which are beyond impeachment. I would suggest, therefore, that series of comparative experiments with each or any of those saline substances, of which I shall speak in the following pages, should be made at different periods and in different successive portions, as follows:—

1°. At different periods—the whole applied at once.

a In autumn, or early winter, when the manure is ploughed in or the seed sown.

The experience of some of the Yorkshire farmers, who apply rape-dust largely to their wheats, is, that the effect is much the same, whether it be harrowed in with the seed in autumn, or

sown as a top-dressing upon the young corn in spring. It may not be the same, however, with other manuring substances, on different soils and upon crops of other kinds.

b In early spring—about the end of March or beginning of April.

c About the end of May or beginning of June, the actual date to be determined by the nature of the plant and the state of its growth.

It is not to be supposed that crops, even when they are considerably advanced, are entirely beyond our reach. Mr William Alexander of Ballochmyle top-dressed a failing crop of beans with a mixture of gypsum and common salt, even *after they were in flower*, and they grew up to be the admiration of the district.

The following scheme represents the form of this series of experiments:—

Nothing.	Applied in Autumn.	In early June.	Applied in April.
In early June.	In April.	Nothing.	Applied in Autumn.

2°. At successive periods—applied in successive portions.

Suppose two cwt. to be the quantity we wish to add per imperial acre, then to one pair of patches the whole quantity should be added at once, and to another pair one-half at each of *two successive* periods, as in April and in May, and to a third pair one-third at each of *three successive* periods. The first application would be as follows:—

Nothing.	$\frac{1}{3}$ of Manure.	$\frac{2}{3}$ of Manure.	Whole Manure.
$\frac{2}{3}$ of Manure.	Whole Manure.	Nothing.	$\frac{1}{3}$ of Manure.

Such general trials as these are likely, when made with various substances in varied circumstances, to lead to useful and instructive results.

§ 8.—*Equivalent quantities or weights of different saline substances used in comparative field experiments.*

In making field experiments, we wish to ascertain, among other points, what are the comparative effects of different substances applied to the same soil and crop under similar circumstances. But in making such comparisons, we are not at liberty to select at random the quantity of a substance A, which we are to apply in comparison with a given weight of a substance B. We must not even apply them in equal weights if we wish to obtain results which can be correctly compared with each other. This is a point which has not hitherto been brought under the notice of practical experimenters, with whom the comparative money value has generally been the standard by which the quantity applied was measured, rather than the relative chemical energies of the substances employed.

It will be granted, I believe, that the action upon the soil and plant, of the various saline and other substances we employ, is a chemical action—though the precise nature of that action may as yet in many cases have escaped us. But if this be so, they must act in definite quantities: for example—

Suppose I wish to try the relative effects of gypsum and sulphuric acid upon a soil abounding in lime, then I must not take equal weights of the two and sprinkle them over the land. The moment the sulphuric acid enters the soil, it combines with lime and forms gypsum, every 100 pounds of the strongest acid of the shops forming about 170 pounds of gypsum. If therefore we add only 100 pounds of gypsum in comparison with 100 of the strong acid, we give the latter an unfair advantage. To be strictly comparative, 170 pounds of gypsum must be tried against 100 of the acid.

Again—suppose a soil very poor in lime, upon which I wish to try whether this substance will produce the best effect, in the state of quicklime, of slaked lime, or of gypsum, it will be understood at once that, to make the experiments comparative,

I must use different weights of all the three. When lime-shells are slaked, they absorb much water and become heavier—100 pounds of shells become nearly 132 of slaked lime; so that for every 100 of the former, we ought to add 132 of the latter. Gypsum, again, contains only 33 per cent of lime, or when burned, 41½ per cent; so that, to try the effects of lime alone in these three several states, we ought to apply on our experimental patches the three substances in the proportions of—

Quicklime,	100 pounds.
Slaked lime,	132 ...
Gypsum, (unburned,)	300 ...
„ (burned),	240 ...

So, of every other mineral or saline substance we lay upon the land, there is a known quantity, special for each, in which it must be applied if the effect it produces is to be compared with that produced by a known weight of some other substance. The numbers in the following table indicate, in pounds, the relative weights in which the substances named, when in their pure and dry state, ought to be employed in comparative experiments with each other:—

	lb.
Sulphuric acid, (strongest of the shops,)	62
Sulphate of potash,	109
Sulphate of soda, (dry or anhydrous,)	89
Do. do. (crystallised,)	202
Sulphate of lime, (common gypsum,)	108
Do. do. (burned gypsum,)	86
Sulphate of magnesia,	155
Sulphate of iron,	162
Sulphate of baryta,	146
Chloride of potassium,	93
Common salt, (chloride of sodium,)	73
Chloride of calcium, (anhydrous,)	70
Chloride of magnesium, do.,	60
Fluoride of calcium, (fluor spar,)	49
Nitrate of potash, (saltpetre,)	127
Nitrate of soda, (dry,)	107
Nitrate of lime, (dry,)	103
Carbonate of potash, (pearl ash, dry,)	87
Carbonate of soda, (common soda of the shops,)	179
Carbonate of soda, dry, (pure soda-ash,)	67
Quicklime, (burned lime,)	36

	lb.
Slaked lime, (hydrate of lime,)	47
Carbonate of lime,	63
Caustic or calcined magnesia,	26
Carbonate of magnesia,	54
Sulphate of baryta,	146
Silicate of potash,	?
Silicate of soda,*	?
Phosphate of potash, (with two of alcali, 2 KO, P_2O_5,)	207
Phosphate of soda, (of the shops,)	437
Phosphate of lime, (apatite,)†	196
Phosphate of ammonia, (with two of ammonia,)	144
Ammonia phosphate of soda,	692
Ammonia phosphate of magnesia,	238
Carbonate of ammonia,	49
Sulphate of ammoniac,	94
Sal ammoniac,	67
Nitrate of ammonia,	100

From the above numbers, it will be easy to calculate how much of any one substance must be used in a comparative experiment against 100 lb. of any other.

§ 9.—*Circumstances which ought to be stated in regard to all soils and localities selected for experiment, on publishing the results of trials made upon them.*

In regard to all soils and localities on which precise and rigorously conducted experiments are made, it will be necessary, to a full appreciation of the results they yield, that, along with the results, there should be published an account, as far as it is attainable, of—

1°. The proportions of silicious or other sand, fine or coarse,—that is, in common language, the degree of lightness of the soil.

2°. The proportion of lime in the state of carbonate, or otherwise. This indicates very nearly the comparative *decomposing energy* of soils otherwise similar.

3°. The proportion of organic, and especially of peaty matter.

4°. The effect of drought upon it—whether it hardens or

* The composition of these silicates, as manufactured, is liable to so much variation, that no constant numbers can be assigned to them. See § 7, chap. ix.

† Burned bones contain 15 to 20 per cent of other matters mixed with phosphate of lime.

bakes in the sun. This is an important quality, in regard to which stiff clays differ very much, and which we cannot as yet infer even from a complete analysis.

5°. The annual fall of rain—the months or seasons during which it falls most abundantly—and whether the year of the experiments was unusually dry, or otherwise differed from the average weather of the district.

6°. On what geological formation the land rests—its physical position or *lie*—its distance from, height above, and general exposure to the sea.

7°. The state of the land as to richness—whether it is thorough drained, or otherwise—the nature of the subsoil when it differs from the surface—the composition of the springs or brooks that water or flow from or through it.

8°. Its recent agricultural history—the place in the rotation occupied by the crop experimented on, as whether oats are after lea trenched or untrenched, or after turnips, &c.—the quality of the farm-yard manure applied to it—and generally any special circumstances by which the culture, the crop, the field, the farm, or the locality are characterised.

9°. Whether the party who describes the experiments himself superintended them, or to what extent.

A knowledge of these circumstances will enable us to judge how far the results are to be considered special or general—how far the same results are to be expected elsewhere, and under what conditions—how far, therefore, similar experiments are likely to be profitable in the average of circumstances, and ought to be recommended to rent-paying farmers.

CHAPTER VI.

Experiments with sulphuric acid and with the sulphates of potash and soda. Proportion of sulphur in all crops. Recorded experiments with sulphuric acid. Suggestions for experiments with this acid. Composition and general properties of the sulphates of potash, soda, lime, magnesia, and iron. Results of experiments with the sulphates of potash and soda. Functions performed in the soil by these substances. Suggestions for experiments with the sulphates of potash and soda applied alone.

§ 1.—*Proportion of sulphur contained in our usually cultivated crops.*

SULPHUR is an indispensable constituent of all cultivated crops. Some contain more of it, and some less; but all require it for their healthy growth, and all obtain it from the soil by their roots. Nearly all soils contain this sulphur in considerable proportion in some of its forms of combination, though, as appears to be the case with every other kind of food necessary to vegetation, it is more easily attainable by the plant, or exists in a more available form in some soils than in others. The important part which this elementary substance plays in the economy of organised nature, may be inferred from the fact, that the wool alone which clothes the sheep now existing in Great Britain, contains *five millions of pounds of sulphur*—as much as is contained in 30 millions of pounds of gypsum.* All this sulphur is extracted from the soil in the herbage cropped by the sheep; the soil, therefore, must contain naturally an almost inexhaustible supply of it, or must have the annually diminishing supply renewed by natural or artificial means.

Messrs Way and Ogston have recently published a series of determinations of the quantity of sulphur contained in several

* *Johnston's Elements of Agricultural Chemistry and Geology*, 5th edition, p. 329.

of our cultivated crops, (*Royal Ag. Jour.*, ix., p. 136,) and another series has been published by Mr Sorby in the proceedings of the Chemical Society. The following table exhibits some of their results:—

A thousand pounds of the different plants, dried perfectly at 212° F., contain—

	In a thousand. Sorby.	In a thousand. Way.		In a thousand. Sorby.
Four species of grass,	1·6	—	Potatoes,	0·9
Rye-grass,	3·2	0·6	Turnips,	4·0
Red clover,	1·0	4·7	Carrots,	0·9
White clover,	1·5	3·7	Cabbage,	4·3
Sainfoin,	—	0·6	Turnip tops,	7·5
Lucerne,	3·3	—	Carrot tops,	7·5
Beans,	0·7	2·9		
Peas,	1·6	2·7		

I do not quote more of these results, as I believe further experiments will show the numbers obtained by these experimenters to be all below the truth. I have caused two combustions to be made of parsnips and cabbage in my own laboratory, with the following results as to the percentage of sulphur in the dried substance:—

	Per cent.
Common parsnip,	0·999
Cabbage, (great York,)	1·58
„ (sugar loaf,)	1·13

These results, which are considerably higher than those of Sorby and Mr Way, give, for the quantity of sulphur carried off the soil by a crop of 20 tons of cabbage, and of 8 tons of parsnip roots, respectively—

Cabbage, (20 tons,)	45 pounds.
Parsnips, (8 tons,)	20 pounds.

As all this sulphur is believed to be drawn by plants from the soil only, there is an apparent reason, therefore—independent of other kinds of action they may be supposed to exercise—why substances containing sulphur in a state in which it can safely enter into the roots of plants should, in certain circumstances, be useful in promoting vegetation.

§ 2.—*Results of experiments with sulphuric acid. New experiments suggested.*

It has been long known that the steeping of seeds in diluted sulphuric acid (oil of vitriol) promotes their germination, and even increases the crop of corn or other produce obtained from them. But the direct application of this and other acids to the soil has not been so much attended to, though good effects have frequently followed from such a use of them.

Diluted sulphuric acid applied to the clover crop has been found, in the neighbourhood of Lyons, to produce the same effects as gypsum did. This is easily intelligible, since, if there was any sensible quantity of carbonate of lime in the soil, gypsum would be formed as soon as the acid came in contact with it: still, the acid might also act in a different way.

In Fifeshire, a fair crop of turnips was obtained by Mr Wood, without other manure, by simply watering the drills with diluted sulphuric acid. This also is not inexplicable, as the land in Fifeshire and the Lothians is, upon some farms, in so high a condition, that it will grow *one* fair crop of turnips without any manure at all.

In Germany, both barley and clover have been found to give larger crops when watered with dilute sulphuric and muriatic acids. I quote some results obtained by Mr Tinzmann, of Silesia, in 1841.

a On clover, applied at the rate of about 7 pounds to the imperial acre (3 loth to 4 square rods Prussian.) The produce from a Prussian morgen (0.631 of an imp. acre) was—

	Hay.	Seed.
Nothing, ...	11 cwt. 50 lb.	$2\frac{1}{2}$ bushels.
And diluted with 100 waters, .	18 ... — ...	$1\frac{5}{8}$ ...
... 200 ...	14 ... 35 ...	$1\frac{5}{8}$ ...
... 500 ...	15 ... 15 ...	$1\frac{1}{2}$ ...
... 1000 ...	16 ... 40 ...	$1\frac{3}{8}$ ...

The increase of hay in all these cases is certainly great, and this increase appears naturally enough to account for the diminution of the seed. The increased and prolonged growth of the leaf and stem, besides covering up the ground more closely,

would delay the ripening and filling of the seed, and thus diminish the weight and bulk of grain produced by a given period of the year. The unmanured might have ripened its seed while the manured was still growing.

The after barley crop, in 1842, reaped from the several portions, was 7 bushels, $11\frac{1}{2}$ bushels, $11\frac{1}{4}$ bushels, $12\frac{5}{8}$ bushels, and $9\frac{1}{8}$ bushels, respectively.

Again, in 1843, he tried the effect of the same acid, at the rate of 9 lb. of acid per imperial acre, (10 loth to 20 square rods,) diluted with 200 of water—compared with that of pure water, and of the same seed steeped 6 hours in the same quantity of acid, diluted with 40 of water, with the following results, per morgen:—

	Grain.	Straw.
Seed steeped in dilute acid, .	$14\frac{7}{8}$ bush.	16 cwt. 76 lb.
Seed steeped in common water,	$11\frac{7}{8}$ ...	14 ... 8 ...
Acid applied with 200 of water,	$11\frac{1}{2}$ ...	14 ... 44 ...
Same quantity of water only,	$11\frac{1}{4}$ ...	13 ... 10 ...
Nothing applied, . . .	$11\frac{1}{4}$ ...	12 ... 84 ...

There does appear to have been a small increase of growth produced by the application of the acid to the soil, though much less than when the seed was merely steeped in it.

The quantities applied by this experimenter appear to have been almost incredibly small, to have produced a sensible effect over a whole acre of ground; and it would, in such a case as this, have been especially desirable that duplicate or triplicate experiments should have been made.

Receiving these results, therefore, in the mean time as curious, and as suggestive of inquiry, the experiments should be repeated,—

1°. With the acid in different and in larger proportions than were used by Tinzmann, and in different degrees of dilution, though 300 or 400 of water by bulk may be considered safe, except in very dry weather.

2°. Applied at different seasons, either all at once on separate trial portions, or in successive small applications, as I have explained in the preceding chapter.

3°. On different soils, such especially as differ in the proportions of lime they contain.

4°. On different crops, either as a watering after the seed is sown, when it has come up and is especially liable to injury from insects, or when, in April or May, the young plants have already attained a considerable size.

Though, as I have already said, the beneficial action of sulphuric acid may be ascribed to its forming gypsum in the soil, yet the reader will understand that the peculiar action of this acid upon organic matter may also be a cause of the sensible effects which follow its application. It may also be because its action is really of this kind, that, when applied in the least diluted state, its effects were the most striking in some of the experiments of Tinzmann. At all events, the possibility of so explaining its action adds to the interest of experiments made with it, and more strongly recommends the prosecution of them.

§ 3.—*Composition and general properties of the sulphates of potash, soda, lime, magnesia, and iron.*

1°. *Sulphate of potash* is colourless; crystallises in double six-sided pyramids; undergoes no change by exposure to the air; dissolves in 9 parts of water at 60° F.; has a slight saline, bitter taste; decrepitates in the fire; is without smell; and produces no sensible action upon animal or vegetable substances. When pure, it consists, in 100 parts, of—

Sulphuric acid, ...	45·93
Potash, ...	54·07
	100

2°. *Sulphate of soda*, (Glauber's salt,) is also colourless, and without smell. It crystallises in long striated four-sided prisms, and these crystals effloresce, or fall to a white powder, in a dry, warm atmosphere. When dry and uncrystallised, however, it undergoes no change by exposure to the air. The crystals dissolve in 14 parts of water at 32° F., but in less than 5 parts at 60° F. When heated, the crystals melt or dissolve in their own water of crystallisation. When free from water, or dry, sulphate of soda dissolves in 20 parts of water at 32° F., and in 7 parts at 60° F. It has a peculiar cooling, bitter taste, and is

without sensible action on animal or vegetable substances. It consists, in 100 parts, of—

	Crystallised.		Dry, or waterfree.
Sulphuric acid, . .	24·85	...	56·18
Soda, . . .	19·38	...	43·82
Water, . . .	55·77		
	100		100

Sulphate of soda is therefore much more soluble, as it is also much lower in price, than the sulphate of potash.

3°. *Sulphate of lime*, (gypsum,) when pure, is colourless, and without appreciable taste or smell. It usually occurs crystallised, and often forms masses of crystals that possess a beautiful satiny fracture and lustre. It undergoes no change by exposure to the air; but when heated to about 300° F., it loses 21 per cent of water, and becomes white, opaque, and much more friable, and easily reduced to an exceedingly fine powder. After being thus burned, it forms what is called burned gypsum, or plaster of Paris. When mixed quickly with water, and poured into a mould, gypsum thus burned absorbs and combines with the water which had previously been driven off by the heating, and forms a somewhat solid sonorous mass,—hence its use for making plaster casts. Crystallised or native gypsum dissolves in about 400 parts of water at 60°, and burned gypsum in about 500 parts.

Sulphate of lime consists in the 100 parts of—

	Native gypsum.		Burned gypsum.
Sulphuric acid, . .	46·31	...	58·47
Lime, . . .	32·90	...	41·53
Water, . . .	20·79		
	100		100

It is cheaper than either of the other sulphates, but much less soluble in water. Its solution in water is very readily decomposed by the presence of organic matter in the water. It is deprived of its oxygen by the organic matter,—is converted into sulphuret of calcium, and thus imparts to the water a sulphury smell and taste. In making use of burned gypsum for experi-

ments, it is of importance that it should not have been over-burned—that is, heated above 300° F.—as then it neither combines readily with water, nor is easily dissolved in the soil.

4°. *Sulphate of magnesia*, (Epsom salts,) is without colour or smell, but has a peculiar disagreeable bitter taste, only a little less unpleasant than that of sulphate of soda. It crystallises in four-sided prisms, which undergo a very slight efflorescence by exposure to dry air at ordinary temperatures, and dissolve in 1½ parts of water at 60°. The solution produces no sensible effect on animal or vegetable substances.

The pure sulphate of magnesia of the shops consists of—

Sulphuric acid, ...	32.40
Magnesia, ...	16.70
Water, ...	50.90
	100

The large percentage of water contained in this salt, and in the crystals of sulphate of soda, as well as their extreme solubility, are important characters of these two sulphates.

5°. *Sulphate of iron*, (green vitriol,) is of a pale green colour, and is without smell; but it has a peculiar styptic taste, characteristic of the salts of iron. When exposed to the air for a length of time, it gradually assumes a rusty appearance on the surface, from the production of peroxide of iron, by the action of the oxygen of the air. It dissolves in 1½ parts of water at 60°, giving a pale green solution, which has no immediately sensible effect upon animal or vegetable substances introduced into it, but which speedily becomes yellow by exposure to the air; deposits a yellow ochrey sediment, and acquires a strongly acid taste.

The sulphate of iron, or green vitriol, consists of—

Sulphuric acid, ...	31.03
Protoxide of iron, . . .	27.19
Water, ...	41.78
	100

§ 4.—*Results of experiments with the sulphates of potash and soda.*

In consequence chiefly of the high price of sulphate of potash, few experiments have, I believe, been made with it, and I am consequently unable to insert any illustrations of the nature of its action. Numerous trials, however, have been made with the sulphate of soda, of which I quote the following:—

1°. On *wheat* after potatoes by Mr Main, East Lothian, in 1846. Applied on the 25th of May, as a top-dressing, alone and in conjunction with animal charcoal, it gave, per imperial acre—

	Grain.	Straw.
Nothing, . . .	37½ bushels.	29 cwt.
Sulphate of soda, 2 cwt.	42 ...	38 ...
Sulphate of soda, 1 ... } Animal charcoal, 1 ... }	43 ...	43* ...

By the same Mr Main, in 1847, on two varieties of wheat.

a On Taunton Dean wheat, top-dressed 1st February, and compared with Peruvian guano—

	Grain.	Straw.
Nothing, . . .	27½	19¼ cwt.
Sulphate of soda, 2 cwt.	32	24¾ ...
Peruvian guano, 2 ...	29½	24 ...

The superiority of its effects to those of the guano is probably to be attributed to the state of the land.

b On Hopeton wheat, in 1847, compared with nitrate of soda—

		Grain.	Straw.
Nothing, . .	—	40 bush.	27 cwt.
Nitrate of soda, .	3 cwt.	50 ...	39¼ ...
Sulphate of soda, .	3 ...	46 ...	33½ ...
Sulphate of soda, . Nitrate of soda,† .	1½ ... } 1½ ... }	43¾ ...	36½ ...

The reader will no doubt regret with me that duplicate or triplicate experiments had not enabled us to judge how far the apparently contradictory result obtained from the mixed sul-

* *Transactions of Highland Society,* January 1848, p. 175.

† *Transactions of Highland Society,* March 1849, p. 530.

phate and nitrate is to be depended upon. A mixture of two saline substances does not necessarily produce a less effect than either of them applied singly. On the contrary, the produce is usually greater,* though theoretical reasoning will satisfy us that it cannot be universally so. It is unfortunate that we cannot rely on single experiments, and are therefore compelled to hold ourselves in suspense in regard even to interesting facts which are not supported by adequate proof.

2°. *On oats*, after turnips, top-dressed 25th May 1846, by Mr A. Main, East Lothian, it gave, per imperial acre—†

		Good Grain.	Light Grain.	Straw.
Nothing, .	— ...	42½	2½ bush.	24 cwt.
Sulphate of soda,	2 cwt.	58¾	3¾ bush.	26¼ ...
Sulphate of soda, 1 ...; Animal charcoal, 1 ...		62¾	5 ...	32 ...
Nitrate of soda, 74¾ lb.; Sulphate of soda, 74¾ ...; Animal charcoal, 74¾ ...		45¾	1¾ ...	26 ...

The effect of the sulphate here was more striking than that of either of the other substances applied, in so far as a single experiment with each enables us to judge. The third result, however, awakens suspicion.

On oats, by Mr Fleming of Barochan in Renfrewshire in 1844—

Nothing, mean of four portions, . .	51 bushels.
Sulphate of soda, 2 cwt. per acre, . .	45 ...

In this negative case only one trial plot was dressed with the sulphate, and the separate results from the five undressed portions are not given.

3°. On *beans*, Mr Girdwood found at Corstorphine, near Edinburgh, that a dressing of 2 cwt. per acre added 16 bushels an acre to the crop; and on Lord Blantyre's farm at Lennox Love in East Lothian in 1843, 1 cwt. per acre increased the crop from 30 to 34 bushels per imperial acre.‡

* *Elements of Agricultural Chemistry and Geology*, 5th Edition, p. 232.

† *Transactions of Highland Society*, January 1848, p. 176.

‡ See Appendix to the first Edition of my *Lectures on Agricultural Chemistry*, p. 96 and 100.

4°. On *mixed tares and beans* cut green, three experiments, made in 1843, gave respectively—

a Mr Fullarton, Forfarshire—

No dressing, ...	88 cwt.
Sulphate of soda, 3 cwt. . . .	$91\frac{1}{4}$ ...

b Mr M'Clelland, Wigtonshire—

No application, ...	·96 cwt. per imperial acre.
Sulphate of soda, 3 cwt. .	107 ... ...

c Mr M'Lintock, Lanarkshire—

No application, ...	136 cwt.
Sulphate of soda, 2 cwt. . . .	200 ...

In all there was an increase, though only in the last was it so decided as, in the absence of double experiments, to satisfy us of its economical value.

5°. On *turnips*, various experiments were made in 1843 with sulphate of soda applied alone, either along with the home manure, or as a top-dressing to the young plants.

a On the purple-topped yellow variety, by Mr Melvin, Mid-Lothian, the sulphate applied with the manure in the drills gave, per imperial acre—

Farm-yard manure, 20 tons, gave	21 tons 10 cwt. of bulbs.
Do. do. 20 tons, Sulphate of soda, $2\frac{1}{4}$ cwt.	22 ... 19 ... ...
Farm-yard manure, 20 tons, Sulphate of soda, 3 cwt.	17 ... 16 ... ...

With two results so contradictory as these, we cannot venture to say that in this case it did any good.

b On Dale's hybrid, by Mr Proudfoot, Mid-Lothian—

Farm-yard manure, 28 tons, gave	14 tons 16 cwt. of bulbs.
Do. do. 28 tons, Sulphate of soda, $2\frac{1}{2}$ cwt.	14 ... 8 ... ...

Another experiment on the same variety, by Mr M'Clelland, in Wigtonshire, also gave no difference in the result. But one, made by Mr M'Lintock, on a field of light sandy loam in poor condition, gave—from

Farm-yard manure, 10 tons,	11 tons 14 cwt. of bulbs.
Do. do. 10 tons, Sulphate of soda, 1½ cwt.	14 ... 18 ... ...
Increase,	3 tons 4 cwt. ...

c Aberdeen yellow turnips gave also, to the same experimenter, from

Farm-yard manure, 10 tons,	8 tons 16 cwt. of bulbs.
Do. do. 10 tons, Sulphate of soda, 1½ cwt.	10 ... 12 ... ...
Increase,	1 ton 16 cwt. ...

d Jones' yellow-top gave to Mr Fleming, of Barochan, Renfrewshire—

Farm-yard manure, 30 yards, . .	26 tons of bulbs.
Sulphate of soda, (top-dressed,) 80 lb.,	28 tons ...
Increase,	2 tons ...

e On Swedes, an application of 3 cwt. per acre gave Mr Haxton, in Fifeshire, an increase of 1 ton upon a crop of 17½ tons; to Mr Bourhill, in Mid-Lothian, an increase of 14 cwts. on a crop of 13 tons; and, to Mr M'Lintock, of 32 cwt. on a crop of 10 tons.

On the whole, therefore, the applications to turnips hitherto published can scarcely be said to have done any sensible good when the application of farm-yard manure was sufficiently large.

6°. On *grass and clover* cut for hay, numerous experiments have been tried, though none with that attention to careful duplicate trials which would justify us in drawing positive conclusions. I have brought together a number of the most trustworthy of these in the following table:—

Name.	Quantity of sulphate per acre.	Produce in Stones per Imperial Acre.	
		Nothing applied.	Sulphate of soda applied.
Mr Melvin, Mid-Lothian, . .	3 cwt.	306 stones.	308 stones.
Mr Fullerton, Forfarshire, . .	3 ...	220 ...	251½ ...
Mr Proudfoot, Mid-Lothian, .	2 ...	364 ...	384 ...
Mr M'Clelland, Wigtonshire, .	2 ...	248¾ ...	282 ...
Mr Haxton, Fifeshire, . . .	3 ...	154¾ ...	186 ..
Mr Fleming, Renfrewshire, .	0¾ ...	400 ...	526 ...
Do. do. .	0¾ ...	222 ...	186 ...
Mr Russell, Fifeshire, . . .	3	192 ...	164 ...

* For the first five experiments, see *Transactions of Highland Society*, January 49, p. 437.

On grass and clover intended for hay, we may also conclude that there are doubts as to the profitable use of sulphate of soda applied alone, though, as in the case of turnips, there are instances among those I have quoted in which it very largely increased the produce.

One remark it is necessary to make in regard to the sulphate of soda applied in all the above experiments. It is generally not mentioned by the experimenter whether the dry or the crystallised sulphate was used. Mr Russell states his to have been the crystallised,—which contains, as we have seen in the preceding section, above 55 per cent of water,—while Mr Fleming used the dry salt, which contains no water; but none of the others draw the distinction. It is obvious, however, that in any future experiments with this substance, the fact of its being crystallised (like common Glauber's salt) or dry, ought to be carefully specified.

§ 5.—*Functions performed in the soil by the sulphates of potash and soda.*

The idea we form as to the functions performed by a substance in the soil or in the plant, will materially determine the kind of experiments we shall consider likely to lead to the most useful results. Before adverting, therefore, to the experiments it may be desirable to institute, it is proper to state briefly the principal functions, in reference to vegetation, which the sulphates of potash and soda may be supposed to perform.

In the *first* place, both of these salts being soluble in water, are capable of supplying, in the form of sulphuric acid, that sulphur which we find to exist in, and which, therefore, must be a necessary of healthy life to the growing plant.

In regard to the plants to which they are likely to be specially useful, therefore, we should expect them to be those which require this element in the greatest quantity, or in which we find it especially to abound. And as 100 parts of the sulphate of potash contain 46, and of the dry sulphate of soda 56 of sulphuric acid, the latter ought to be the more serviceable, weight for weight, in so far as this supply of sulphur is concerned.

Second, But both salts will also yield alkaline matter, potash, and soda, to the plant. And as our cultivated crops usually abound more in potash than in soda, the sulphate of potash appears likely to exercise a more decided and generally useful action than the sulphate of soda. This forms a proper subject for comparative experiments.

It is to be observed, both of the acid and of the alkali contained in these salts, that, supposing them to have reached its sap, they not only contribute directly, and as so much necessary matter, to build up the several parts of the plant, but they perform chemical functions besides, which, though not well understood as yet, are believed to be necessary to healthy and rapid growth. Whether to some plants (the leguminous plants, for example) the sulphuric acid is more necessary than to others, or more at some periods of their growth than at others, or whether to some the special chemical action of potash is more useful than that of soda—these are points which remain to be cleared up by future experiment and observation.

Thirdly, As it is through the agency of alkaline matter that the silica, so necessary to our straw and hay crops, is rendered soluble, and capable of being conveyed into the sap of plants; and as the alkaline sulphates are capable of undergoing such changes in the soil as may cause their alkalies to combine with the silica in which the soil usually abounds—it is not at all unlikely that these salts may owe part of their action upon vegetation to the capacity of supplying potash or soda for the purpose of conveying silica to the growing plant.

Two things, besides, the reader will bear in mind—that their efficacy for any of the above purposes will depend very much upon the proportion of potash, soda, and sulphuric acid already present in the soil, and that the comparative action of the two sulphates will be modified very much by the greater solubility of the salt of soda.

§ 6.—*Suggestions for experiments with the sulphates of potash and soda, applied alone.*

1°. To the practical man who carefully studies the preceding section, it will appear that there is reasonable ground for

believing that sulphate of soda will, upon certain soils—and possibly upon his—prove a profitable application to certain crops.

a As a top-dressing upon wheat or oats, applied in early spring in a quantity not exceeding 2 cwt. of the dry, or 4 cwt. of the crystallised salt. He may, however, by way of experiment, try the effect of sowing it along with the seed, either all at once, or only one-half with the seed, and the other half when the young crop begins to shoot in spring. The degree of humidity of the local climate will have its influence upon the efficacy of either method.

b On beans, peas, and tares, either harrowed in with the seed, applied in the drills along with the manure, or as a top-dressing along the rows, after the plants are up, and previous to the hoeing.

On clover and grass and turnips, its action does not appear to have been so generally favourable; the practical man, therefore, will use his own discretion as to the propriety of expending money in the purchase of this sulphate as a sole application to these crops.

2°. But to the scientific agriculturist, there are many trials to be recommended with the two sulphates of potash and soda. I enumerate a few.

a We have no carefully conducted duplicate or triplicate experiments with either of these substances upon any crop; any such, therefore, which may now be made and published will be a gift to science.

b Especially experiments are desirable on the comparative effects of the two sulphates in the same circumstances, and upon the same crops and soils.

c Applied in different quantities—at different seasons of the year—all at once—and in successive portions.

d On soils possessing different physical, calcareous, and general chemical conditions.

e Are their effects greater on leguminous crops generally, or on corn crops—what is the difference of the two sulphates in this respect—and what their respective effects compared with those of gypsum?

f Cabbage, parsnips, and probably beet, mangel-wurtzel, and onions, appear to contain a more than usual amount of sulphur. Have these sulphates, therefore, or either of them, any special action upon such crops?

g The hop delights in woollen rags, in which sulphur is a comparatively large constituent, (5 per cent;) will this plant be grateful for an application of sulphates, either alone or mixed with the other manure applied to it?

h Is the quality of a crop—its flavour, its nutritive properties, or its chemical composition—affected by the application of these salts?

The field of experiment here indicated is sufficiently wide, and no good experiments on any of these topics will be without their use. The experimenter, however, must bear in mind, that in many cases he will be unable to judge of the actual effect of these sulphates till the crop is reaped or gathered, and weighed. The sulphate of soda does not darken, but rather pales the green colour of the plants treated with it, and often diminishes their succulence instead of increasing it, as the salts of ammonia and the nitrates do.

Finally, in comparative experiments with the two sulphates, it is of importance to *apply them in proportions which shall contain the same quantity of sulphuric acid*, for only then can their effects be strictly comparative. The chemical reader will at once understand the reason of this. To the unscientific reader it may be sufficient to state—in addition to what he will find in the preceding chapter, § 8—that equal chemical effects are not produced by equal weights of the potash and soda which these two sulphates contain, but by the quantities which are combined or contained in the salts along with equal weights of acid.

Hence, if we apply a quantity of each which contains, say 50 lb. of acid, not only will the amount of chemical effect which the acid may produce be the same in both, but the potash in the one will be able to produce the same amount of chemical effect as the soda in the other. And thus, whether we ascribe the effects they may appear to have upon the soil or plant to the acid or to the alkali they contain, the effects of the two

substances will be strictly comparative. This is a point never hitherto taken into account in agricultural experiments, but it is one of great scientific importance.

In all such comparative experiments, therefore, with these substances, we ought to employ

Against 100 lb. of sulphate of potash,
82 lb. of *dry* sulphate of soda,
or 184 lb. of crystallised sulphate of soda.

CHAPTER VII.

Experiments with gypsum and with the sulphates of magnesia and iron. Results of experiments with gypsum applied alone. Theory of the action of gypsum. Why it does not produce equal effects everywhere and on all crops. Suggestions for experiments with gypsum applied alone. Proportion of magnesia contained in our usually-cultivated crops. Theory of the special action of sulphate of magnesia. Suggestions for experiments with sulphate of magnesia. Suggestions for experiments with sulphate of iron.

§ 1.—*Results of experiments with gypsum applied alone, and in the different months of spring.*

IT is conceded—I may say established—that gypsum has a remarkably fertilising effect when applied to certain crops on certain soils. In Germany, its beneficial action upon clover is proverbial, and in North America it is applied successfully to crops of almost every kind. It is there said "to equalise the value of lands, by rendering those which are naturally poor almost as productive as the rich."* When its use was first introduced into the United States by Dr Franklin, it was imported by his countrymen from Paris: it is now found in the State of New York, and largely in Nova Scotia, from whence it is shipped in large quantities to different parts of the Union.

The number of accurate experiments upon the effects of gypsum applied alone, which I find upon record, is comparatively small. I quote nearly all that have been published of late years in this country.

1°. *Upon red clover.* Mr Smith of Tunstal, near Sittingbourne, dressed his clover at the rate of 4 cwt. per acre, and obtained of hay from the

	1st Cutting.	Seed.	2d Cutting.
Undressed, . .	20 cwt.	20 lb.	5 cwt.
Gypsumed, . .	60 ...	105 ...	22¾ ...
Increase, . .	40 cwt.	85 lb.	17¾ cwt.†

* *Nicholson's American Farmer's Assistant*, p. 217. † *Brit. Husb.*, i. p. 322.

2°. *On mixed red clover and rye-grass*, cut for hay. The following table exhibits the effects of gypsum in different localities :—

Name.	Produce per Imperial Acre in Stones.		Quantity applied.
	No application.	Gypsumed.	
Mr Jamieson, Turriff, Aberdeen,	208 stones.	213 stones.	2 cwt.
Mr Strachan, Gamerie, do.	434 ...	436 ...	2 ...
... Rothie Brisbane, do.	281 ...	287 ...	2 ...
... Mill of Laithers, do.	353 ...	373 ...	2 ... *
Mr Melvin, Ratho, Mid-Lothian,	306 ...	269 ...	4 ...

None of these experiments are very encouraging as to the use of gypsum on mixed grasses in the localities mentioned. In regard to the result of Mr Melvin, the apparent lessening of the crop is to be regarded as an indication either of a difference in the soil or of an error in the experiment, rather than as a proof that the gypsum could exercise an injurious influence. It is by no means impossible for it to exercise such an influence; but the extensive experience of the United States is opposed to the opinion that any application of it can do harm, though it may fail to produce any sensible effect. A result like that of Mr Melvin, therefore, only suggests the propriety of new experiments.

I find in the *American Agriculturist*, (1840, p. 145,) the particulars of an experiment on grass growing on clay land, which I insert because of its being intended to show the effect of gypsum applied in the different months of spring. Ten square perches of a field of grass were measured off, arranged and numbered as below—

1	3	5	7	9
2	4	6	8	10

* These four experiments were made in 1843, on different soils, under the direction of the Turriff Agricultural Association.

To the lower, or even-numbered portions, nothing was applied, but to each of the others, half a pint of gypsum at different dates, with the following results in hay, compared with the immediately adjoining plot. The whole was cut on the 18th of July:—

No. 2	gave	18¼ lb.	No. 1,	dressed	March	18,	gave	19 lb.,	or	¾	lb. increase.
4	...	22½ ...	3,	...	April	3,	...	25½	...	3	...
6	...	21¼ ...	5,	...	...	16,	...	23½	...	2¼	...
8	...	21¾ ...	7,	...	May	2,	...	22½	...	¾	...
10	...	21½ ...	9,	...	...	18,	...	28	...	6½	...

The plots here were too small; but the point deserving of remark, and for which chiefly I have inserted the experiment, is the large increase on the portion top-dressed after the middle of May. This certainly deserves further experimental investigation.

3°. *On wheat*, after gypsumed clover—an experiment is quoted in *British Husbandry*, i. p. 324, in which the dressed and undressed portions of the same field gave respectively, per imperial acre—

Gypsumed, ...	38 bushels.
Undressed, ...	20 ...

being an increase of 18 bushels; but it is not usually recommended, in this country, as a direct application to corn crops. In the United States, at the rate of one or two bushels an acre, it is a very common application to wheat. In consequence of the more luxuriant growth, however, plastered wheat is said to be more subject to rust.

4°. On mixed *tare and bean crops*, cut green, compared with sulphate of soda, it gave the following results per imperial acre:—

a Mr Fullarton, Forfarshire—

Nothing	produced 88 cwt.
Sulphate of soda, 3 cwt., . .	... 91 ...
Gypsum, 1⅔ cwt., . . .	... 101 ...

b Mr M'Clelland, Wigtonshire—

Nothing	produced 96 cwt.
Sulphate of soda, 3 cwt., . .	... 107 ...
Gypsum, 6 cwt., . . .	... 120 ...

c Mr M'Lintock, Lanarkshire.

Nothing	produced 136 cwt.
Sulphate of soda, 2 cwt., . .	... 200 ...
Gypsum, 8 cwt., . . .	... 189 ... *

The numerical results above given are far from being satisfactory; and it is obvious that, if any *scientific* results are to be extracted out of field experiments with this substance, all the necessary experiments are yet to make. Practice is so far satisfied, that in certain districts no doubt exists as to its being a most profitable application; but it is not so everywhere, or in regard to all soils, or to all crops. Both practice and science, therefore, require further explanations as to what crops it especially favours—how, why, where, when, and to what precise extent. To give a sure basis for such explanations, we must possess the results of varied experiments skilfully devised, conscientiously conducted, and rigorously tested by weight and by measure.

§ 2.—*Theory of the action of gypsum. Why it does not produce equal effects everywhere and on all crops.*

These two questions have given rise to much discussion, and to many differences of opinion. The simplest answers to both questions were those given by Sir Humphry Davy, that those crops which naturally contained, and therefore were presumed to require for their natural growth, the largest proportion of gypsum or of sulphur, were most likely to be benefited by an application of this substance, and that those soils in which a sufficient supply of gypsum already existed, would be least grateful for it when spread upon them. This explanation appeared to be confirmed by the analyses which he and other chemists subsequently made. These showed that gypsum does actually exist in our clover crops, and that soils, upon which the use of it produced no profitable effects, actually contained gypsum already. But various facts, observed from time to time, have been considered to throw doubt on the opinion of

* *Transactions of Highland Society*, January 1849, p. 439.

Davy, and to demand that the question should be further considered and explained. Among these I may mention,

a That it produces the most sensible effect on a clover field well covered with herbage, when it is strewed on a calm day so as to rest on the surface of the leaf. In reference to this fact, Peschier of Geneva states, that the green leaf decomposes and converts into carbonate the sulphate of lime which rests upon it.

It is certain, however, that it does much good in many districts, when harrowed in with the seed, or put in, as is so extensively done in North America, in spoonfuls with the potato seed and with the Indian corn at the period of planting.

b That heavy rain, after the application of gypsum, often prevents any visible action for the season.

c That it succeeds better on light, dry, open, and sandy soils—on heavy land doing little good.

d That clover in reality contains no more sulphur than other crops. This is the result of analyses made by Messrs Way and Ogston; and, if confirmed, ought to form an important guide to us in accounting for the special action of gypsum upon this crop.

I shall therefore briefly discuss these two questions—

1°. *Theory of the action of gypsum.* In explaining its action, in a satisfactory manner, it is of consequence to bear in mind—

a That upon soils which already contain much lime, even upon chalky soils, plaster often greatly improves the crop. In such cases, it can scarcely do so, one would suppose, because of the lime it contains. Besides, it requires a comparatively large application even of quicklime to produce any sensible effect upon a field; and yet half a hundredweight of gypsum upon the acre will not unfrequently produce a distinct increase in the luxuriance and ultimate weight of a crop.

Our attention, therefore, is directed to the other constituent, the sulphuric acid, as the active ingredient in such cases. Direct experiments, also, though not usually made with the requisite accuracy, appear to confirm the conclusion to which we are thus led. Thus Mr Tinzman, whom I have previously quoted, made in 1842 a comparative experiment upon clover with gypsum and sulphate of baryta, applied in equal weights,

and obtained a slightly increased and nearly equal produce by each application. The experiment, however, is by no means decisive, and deserves repetition. As baryta cannot be supposed to benefit vegetation—at least as a food to the plant—any action which the sulphate of baryta exercises ought to be ascribed to its sulphuric acid.

b That sulphuric acid is capable of acting both in reference to the soil and to the plant in two ways at least. If the soil be deficient in this acid, the gypsum will supply it as any other sulphate would do. It will also yield to the growing plant that quantity of sulphur or of sulphuric acid which are necessary to the composition and formation of its several parts. But the acid may likewise exercise a chemical action of a salutary nature upon the constituents of the soil, so as on the whole to make them more available to the plant. And, in the plant itself, besides contributing directly to the production of its parts, it may act as a chemical agent in producing changes upon the ingredients of the sap which may materially aid its growth.

c That gypsum, as a sulphate of lime, may, in the plant, perform a very different chemical function from either of its constituents. It is so in the human body. Neither lime nor sulphuric acid taken internally produce the same physiological effect on the system as gypsum does. Neither would chlorine or sodium produce any of those salutary consequences which common salt, so grateful to all animals, is known to do. So no doubt gypsum, introduced directly into the sap of a living plant, would produce an effect greatly different from those which would follow the introduction of either lime or sulphuric acid. Instead of disputing, therefore, as some are inclined to do, whether it is the one or the other of its constituents to which the special action of gypsum is always owing, it is wise to bear in mind that the compound body, sulphate of lime, like all other compound bodies, is capable of performing functions and acting in reference to other chemical bodies, in a way in which neither of its constituents could act, and that to this mode of action its peculiar virtues may occasionally be owing.

One of the properties of this compound is, that, in a moist state, it is capable of decomposing carbonate of ammonia, form-

ing sulphate of ammonia and carbonate of lime. Believing ammonia to exist largely in the air, Liebig explained the beneficial action of gypsum by its absorbing and fixing (forming *sulphate* with) this ammonia. But the answer to this novelty was easy. If this be the action of gypsum, why does it benefit clover and not the adjoining crops, since ammonia is beneficial to all—and why is good done by it on one soil and not on another, since all which are poor in nitrogenous matters are thankful for ammonia?

2°. *Why does gypsum not produce equal effects on every soil?* The general action, as well as the special local effects of gypsum, are to be explained by reference only to a considerable variety of circumstances. Thus,

a If a soil naturally abound in gypsum, or if the springs or streams which water it do so, it is plain that, according to whatever theory we explain the actual effects of gypsum upon plants, the addition of gypsum to such a soil can produce no sensible effect. And as the soils and springs which are associated with certain geological formations—the new red sandstones, and sometimes the mountain limestones, (Nova Scotia,) and old red sandstones, (Russia,) for example—are especially liable to abound in gypsum, it is probable that, from geological maps, we may, in many cases, obtain important hints as to where the use of gypsum is likely to fail in benefiting the farmer.

b If a soil be so poor in lime that it is unable readily to supply as much as a given crop requires, then the addition of gypsum may do benefit by affording the means of readily supplying this want of the plant. The same remark applies to the other ingredient of gypsum, its sulphuric acid; and there is little reason to doubt that the good effects of gypsum are, in many cases, to be ascribed to its readily yielding both lime and sulphuric acid to the growing plant.

c If the manure usually applied has contained a sufficiency of sulphur in any form—if gas lime, for example, has been used, or woollen rags to any extent, or peat ashes, or pyritous marls—in all such cases as these, the apparent effects of gypsum are likely to be lessened. There are, therefore, many circumstances to be inquired into and investigated before we can satisfactorily

say why in this locality it has succeeded, while in that its application has done no good.

d It is possible that there may be variations in the quality of the gypsum itself—that a difference may arise from using it, burned or unburned—that some samples of it may naturally contain more common salt than others, since, in nature, it is very commonly associated with salt; and so on.

In an experiment made by Arthur Young, the produce of two perches of clover dressed, the one with native and the other with burned gypsum, differed only by two pounds when cut green.* In some countries also, as along the banks of the Rhine, equal effects are said to be obtained by it in either form; while others again state, and among these M. Soquet, who has made experiments on the subject,† that, on their soils, unburned gypsum produced no effect whatever.

e The weight of evidence is, I think, in favour of the idea that gypsum does exercise a special action upon the green clover leaf. If this be so, then even upon soils in which it abounds, and which can readily and abundantly supply it to the root, benefit may arise from sprinkling it over the surface of the crop when its leaves have begun to cover the ground; though, if applied to the soils themselves, we could scarcely expect it to do any sensible good.

f I only further put it as a question, whether exposure to the sea may not account for the feeble action of gypsum in circumstances where we, on other grounds, should expect it to do good.

Sea-water contains a small proportion of gypsum, and the sprinkling of this water over the surface of the land, as our stormy sea-winds do, may, in some places, anticipate and prevent the natural effects of gypsum when applied to the soil by the hand of man.

Thus there are gradations in the benefit which gypsum may produce. *First*, None at all if applied to soils which already contain it abundantly, or which are watered by springs that contain it, or are exposed to seas which sprinkle it over the land. *Second*, Even on these spots, a little benefit if, instead of being

* *Annals of Agriculture*, xiv., p. 319, quoted in *British Husbandry*.

† PUVIS, *Des differens Moyens d'Amender le Sol*: Paris, 1837, p. 89.

mixed with the soil, it be strewed in spring over the young green leaves. *Third*, A greater advantage if, at the same time, the soil is deficient in lime or in sulphuric acid; and, *fourth*, The greatest of all if the soil is deficient in both.

3°. *Why it does not act equally on all crops.* I explain this, and, indeed, its general effects, by the conjecture—for I do not wish to state it more strongly at present—that the compound which we call gypsum contains its constituents in a state in which they are specially adapted to enter into and aid in the growth of particular plants. It is not enough, I believe, to place within the reach of our crops the various elementary bodies or binary compounds which we find in plants. These are, we now know, very nearly the same in all. It is chiefly in proportion that the mineral constituents of plants differ. We must discover and apply these substances also in the state of combination in which they are severally best suited to enter into—to find admission perhaps I ought to say—into the roots of each particular genus or species of plant, and to be physiologically, chemically, and structurally useful to it after they obtain admission into its sap.

We appear to have ascertained by trial that, in a great variety of circumstances, gypsum has this special adaptation to certain plants. If this be so, it is an ultimate fact of much interest, which explains many anomalies, and may point the way to other interesting discoveries of a similar kind. I have already briefly alluded to this topic,* and shall have occasion, in a succeeding chapter, to return to it, to consider what evidence we possess in favour of the opinion I have thrown out, and what experiments may be suggested with the view of investigating and shedding further light upon it.

§ 3.—*Suggestions for experiments with gypsum, applied alone.*

The field of experiment with this substance is very wide. I shall advert to a few of the points it may be most interesting to investigate.

1°. To the practical farmer it may be recommended for trial in small experiments on his different soils, and especially on

* See Chapters IV. and V.

red clover, sainfoin, and lucerne. This clover it is said to cause to stock out, or tiller; and if strewed on young peas, as they are looking up, to cause the production of larger crops. For all leguminous crops it is praised, and by many for Indian corn and for hemp. It is better to sprinkle it on the green leaves of clover on a calm afternoon. On light dry soils it does best; on cold, heavy, or wet land, on such as is exhausted, or which contains little organic matter, its effects are small. The gardener may apply it to his strawberries, which, in the United States, are greatly improved by it.

2°. The scientific man can make no rigorously accurate experiment in duplicate or triplicate the result of which will not be an acquisition. But he may—

a Compare the effects of gypsum in its different states upon red clover, thus—

Nothing.	Burned below 300°.	Unburned.	Overburned, or above 300°.
Unburned.	Overburned, or above 300°.	Nothing.	Burned below 300°.

b Applied at different periods of the spring. In a small experiment by Körte, the produce of clover was greater when the gypsum was laid on at the end of April than at the end of March. The same was the case with the American experiment quoted in the preceding section. It is desirable, however, that this result should be tested by repeated careful trials.

c Applied to the soil itself, or sown along with the seed, or spread upon the leaves early and late in spring, thus—

Nothing.	Spread in April.	Sown in the soil.	With the seed.	Spread in May.
With the seed.	Spread in May.	Nothing.	Spread in April.	Sown in the soil.

Has it really one action when applied to the root in the soil, and another different chemical action when applied to the leaf in the air? If so, these experiments will exhibit it.

d Compared with diluted sulphuric acid, and with the sulphates of soda, potash, magnesia, and baryta, or with one or more of them, in the proportions expressed by the numbers in section 8, Chapter V.—namely,

Strong sulphuric acid, ...	62 lb.
Sulphate of potash, ...	109 ...
Sulphate of soda, (dry, or anhydrous,) .	89 ...
... ... crystallised, . .	202 ...
Gypsum unburned, ...	108 ...
... burned, ...	86 ...
Sulphate of magnesia, ...	155 ...
Sulphate of baryta, ...	146 ...

The mode of making these comparative experiments has already been described, and the object or purpose of them is sufficiently obvious.

e Is its action really special upon *all* leguminous crops, or is its peculiar action confined to a few of these? Does it show no marked influence upon the growth of any of the grasses or corn-bearing plants, or on any of our root-crops? Or does it exhibit such an effect only on some soils or in some climates?

These inquiries alone involve a large extent of experimental research. Given by experiment that in a certain soil it peculiarly favours the growth of clover, will it equally favour also that of tares, peas, beans, and of leguminous shrubs and trees? Again, will it in the same soil produce a less sensible effect on wheat, oats, barley, rye, Indian corn, &c.? And again, what effect in the same soil will it have upon turnips, carrots, parsnips, beet, mangel-wurtzel, cabbage, radishes, &c., either put in along with the manure, or with the seed, or strewed on the leaves when they are more or less fully expanded?

How many carefully conducted experiments will it require to determine all these points, and especially if we consider how very much they may be extended and varied?

f The effect of gypsum in soils which are rich and in others which are poor in lime. To ascertain this precisely, in regard

to soils in which the proportion of lime has been determined by analysis, might help us towards clearer views as to the agency of the lime contained in gypsum.

Again, is its effect less upon land which has been regularly limed? I have elsewhere shown that all our limes contain gypsum, and that the natural presence of gypsum upon limed land may modify the action of this substance when afterwards directly applied to it.* I need only indicate the companion series of experiments upon soils more or less rich in sulphuric acid, in any of its states of combination.

g Peas and beans are known to be sometimes what are called good, sometimes bad, boilers—to boil sometimes hard, and sometimes soft and mealy. Gypsum is accused, while it promotes their growth, of imparting this quality to tares, peas, common beans, and haricots. Is the accusation just? has it such an effect upon any of these crops? Have waters which contain gypsum the property of hindering the boiling of legumes?† and will a little soda prevent this effect? Experiments on these subjects are easy to make. They require only a testing of the quality of such crops as have been doctored with gypsum, applied in weighed proportions, at different seasons and on different soils.

h Experiments with gypsum as a fixer of ammonia.—I have already explained, in the previous section, that gypsum, when moist, has the property of decomposing carbonate of ammonia, and forming a sulphate of ammonia which is fixed—not volatile, that is, or likely to fly off into the air as the carbonate does. In consequence of this property of gypsum, it has been much recommended as a means of removing the smell of stables, and preventing the escape of ammonia from dung-heaps. The practical man may try experiments of this kind, and possibly

* See *The Use of Lime in Agriculture*, pp. 212, 248.

† This is a very old opinion. Thus Palladius alludes to it in his section on *The proving of water*:—"You will prove new water thus—you sprinkle it over a clean brazen vessel, and if it makes no blur it may be discovered to be proof. Being boiled, also, in a brazen vessel, if it leaves no sand or mud at the bottom, it will be good for use; if it also *boils pulse soon*, or if it is pellucid, free from moss and from every mark of pollution."—(*Agriculture of Palladius*, translated by OWEN, book ix., § 10.)

with advantage: there is one point, however, to which I would draw the attention of the scientific agriculturist.

Gypsum, in the presence of water and organic matter, is very readily deprived of its oxygen, and converted into sulphuret of calcium. In the baths of Louesch, the warm waters (80° to 90° F.) are sulphureous, though, as they issue from the spring, they contain only sulphates, and chiefly gypsum.* The contact of the skins and perspiration of the patients who bathe in it, and live in it, I may say, six or eight hours a-day, produces this change. In manure-heaps, in which gypsum is covered up, a similar change must take place, and one or more of several effects will follow.

First, The carbonic acid produced in the fermenting mass will decompose this sulphuret, forming carbonate of lime, and evolving sulphuretted hydrogen, thus increasing rather than diminishing the smell. Or *second*, The carbonate of ammonia given off in the heating mass will decompose the sulphuret of calcium, forming carbonate of lime and hydro-sulphuret of ammonia. This latter has a smell, and is by no means fixed, supposing its existence to be permanent. But the carbonic acid produced will decompose it also, and form carbonate of ammonia, again evolving sulphuretted hydrogen. Or *thirdly*, The sulphuret of calcium will expend its sulphur so far, in combining with all the iron which the manure may contain, giving it a blacker colour and more decomposed appearance, but not fixing its ammonia.

While therefore it is true that, when strewed on the surface of moist fermenting heaps, gypsum in fine powder may arrest and fix the ammonia which is escaping, it is deserving of inquiry how far it serves any good purpose, other than that of adding lime to it, when it is actually mixed with the fermenting manure. If there be anything in this reasoning, it may account for different opinions and results, and is, I think, not unworthy of being experimentally tested by some one who has the requisite chemical knowledge, and has the means of devoting to the experiments the requisite time and attention.

* FONTAN. *An. de Chem. et de Phys.*, (1840,) xxiv., p. 280.

Three equal weights of the same manure, fresh as it is taken out of the fold-yard, and as equably mixed as possible, should be placed for two or three months in the same circumstances. One of the three portions should be immediately mixed with a weighed quantity — say two or three hundredweight of gypsum to 20 tons of manure—and at the end of the three months, all the three portions should be used on the same soil for the same crop — treated in every way the same. Three duplicate experiments must be made: two with the manure with which the gypsum has been mixed, two with the manure in its natural state, and two more with this manure, plus a quantity of gypsum applied to the soil after or along with it, and equal to that which the gypsumed manure contains. This latter addition is for the purpose of testing and eliminating the effect which the mere addition of gypsum, irrespective of any chemical action, would have upon the manure, the soil, or the crop. The following scheme shows the arrangement:—

Manure alone.	Manure and gypsum.	Gypsumed manure.
Manure and gypsum.	Gypsumed manure.	Manure alone.

I think such experiments as these would set at rest the value of the theoretical view I have above stated, as well as the question as to the economical value of gypsum used in this way, to the practical farmer.

There is still another point to which attention should be drawn. One or two hundredweight of gypsum are said to produce as good an effect as a larger dose, but that larger doses do no harm. Are these statements correct? Are they so in regard to all soils, crops, seasons, and climates? Accurate experiments should be made as to the effects of gypsum when applied—

First—in different doses to the same crop on the same

soil—from one to ten or twelve hundredweight an acre, for example; and

Second—on different crops, applied also in increasing doses.

The facts above stated will thus be tested, and also whether, if true of one, they are also true of other crops.

§ 4.—*Results of experiments with sulphate of magnesia applied alone.*

Of published experiments made with sulphate of magnesia applied alone, the following are nearly all which have come to my knowledge:—

1°. *On oats, a* By Mr Main, at Whitehill, Mid-Lothian.

		Per bush.
Nothing gave . .	42 bush., weighing	40 lb.
Sulphate of magnesia, 2 cwt.,	56	37½ lb.

b By Mr Fleming of Barochan, Renfrewshire, on land trenched with the spade out of a nine years' old lea.

	Grain.	Straw.
Nothing, (mean of 4 plots,) .	51 bush., weighing	30 cwt.
Sulphate of magnesia, 2 cwt., .	47	28⅓ ...
Sulphate of soda, 2 cwt., .	45	29½ ...*

The experiment of Mr Main is favourable; but we cannot rely upon either of them, from the want of duplicate experiments. At Barochan, the land ought to have been sufficiently rich naturally; but we are unable to judge of the exact effects, because we have neither duplicate results of the effects of the two sulphates, nor the exact produce of each of the four plots to which nothing was applied. Some of these four might yield less than either of the dressed plots; and if so, the apparent lessening effect of these saline applications would disappear.

2°. *On clover and rye-grass*, cut for hay by Mr M'Lean, Braidwood, Mid-Lothian, in 1842.

Nothing, ...	125 stones per acre.
Sulphate of magnesia, 1½ cwt., . .	290 ... ...
Gypsum, 3 cwt., ...	200 ... ...†

The value of these results is somewhat diminished by their

* *Transactions of the Highland Society,* March 1845, p. 421.

† *Ibid.* July 1843, p. 34.

being obtained from patches of only 1-20th of an acre each.

3°. *On turnips*—*a* By Mr M'Lean, Braidwood, Mid-Lothian, in 1842—variety, yellow turnips.

	Per acre.
Farm-yard manure, 30 carts produced	24 tons.
Do., 15 carts, with ½ cwt. of sulphate of magnesia mixed with it, ...	25 ...

This result is very favourable.

b By Mr Fleming, Barochan, Renfrewshire, in 1842—variety, early Liverpool yellow turnips.

Nothing, 1st plot, . . .	11 tons	8 cwt.	of bulbs.
... 2d plot, . . .	12 ...	17 ...	...
Sulphate of magnesia, 1 cwt., .	14 ...	17 ...	...
Sulphate of ammonia, 1 cwt., .	24 ...	11 ...	...
Nitrate of soda, 1 cwt., . .	27 ...	2 ...	...

This field was trenched out of grass, and received no farm-yard manure. Nothing shows more clearly the difference in the quality of land than the small crops of turnips, which I have had occasion, in my previous sections, to quote as being produced, even after the application of manure, compared with the production of nearly 13 tons by this field without any manure. The doctored returns, however, especially those obtained by the use of the sulphate of ammonia and nitrate of soda, are sufficiently surprising, and cause us to regret that the experiments were not made so carefully, in duplicate or triplicate, as to justify us in placing complete reliance upon them. I trust, however, they will awaken in others a desire to repeat them on land similarly treated.

4°. *For potatoes* sulphate of magnesia has lately been much lauded. The following are the only two experiments having pretensions to accuracy which have as yet come under my notice. They were made by Mr Fleming of Barochan in 1842, and were intended to test the comparative advantages of this substance when applied as a top-dressing to the young plant, and when mixed with the manure at the time of its application. The results were, per imperial acre—

a Farm-yard manure, 40 cubic yards, produced	12 tons 15 cwt.
Do. do., with 1½ cwt. sulphate of magnesia, applied as a top-dressing, ...	13 ... 5 ...
b Farm-yard manure, 36 cubic yards, . .	8 ... 17 ...
Do. do., and 2 cwt. sulphate of magnesia mixed with the manure, ...	11 ... 7 ...

In both these cases, the results appear favourable; in the latter decidedly so. At all events, they justify the institution of new and more extended trials.

On the whole, we may say that nothing very positive has yet been ascertained as to the effect of sulphate of magnesia upon our usually cultivated crops, when it is applied alone. There are reasons for anticipating, however, that, in certain circumstances, it should produce a favourable effect, especially upon our grain crops.

§ 5.—*Proportion of magnesia contained in our usually cultivated crops. Theory of the special action of sulphate of magnesia.*

1°. *Proportion of magnesia.*—The principal reason for the anticipation stated at the close of the preceding section, is the large proportion of magnesia which is present in the ash of many of our cultivated, and especially of our grain crops. This is exhibited in the following table:—

Proportion of magnesia in the ash of—

	The grain or bulb.	The straw or top.
Wheat, ...	12·0 per cent.	3·8 per cent.
Barley, ...	7·5 ...	3·2 ...
Oats, ...	10·0 ...	3·8 ...
Rye, ...	10·4 ...	2·4 ...
Beans, ...	6·5 ...	7·6 ...
Pease, ...	6·6 ...	6·7 ...
Flax, ...	14·5 ...	8·0 ...
Potato, ...	5·3 ...	7·0 ...
Turnip, ...	2·7 ...	2·8 ...
Mangel-wurtzel, . .	2·1 ...	8·6 ...
Carrot, ...	4·0 ...	2·9 ...

The seeds of our corn plants and of flax appear, from this table, to contain more magnesia than beans or pease do, and much more than is present in our root crops. In pulse and root crops, lime generally exists in much larger proportion than magnesia.

Among root crops, however, there are differences. The potato contains more magnesia than the turnip, while the mangel-wurtzel, also, contains in its leaf more magnesia, but is not, either in leaf or bulb, so rich in lime as the turnip and carrot are.

2°. *Theory of the action of sulphate of magnesia.*—If this salt exercise any special action upon vegetation, it may arise from either of three causes.

a From its extreme solubility, which enables it more readily to enter into plants, and thus to supply them with either of its constituents—sulphuric acid or magnesia.

b From its supplying magnesia to those plants which specially require it. In this case it ought to be grateful to our wheat and other corn plants, and, among our roots, to the potato more than to the turnip and carrot. On the bean, the pea, the turnip, and the carrot, the comparative action of gypsum ought to be greater than that of sulphate of magnesia; while, to the mangel-wurtzel and the beet, the two salts ought to be equally, though neither of them largely, propitious.

c From its peculiar properties as a chemical compound. Like other saline substances, it may act as a compound body in a way which is not to be inferred from what we know of its constituents,—a mode of action which I allude to as only conjectural, yet deserving of rigorous experimental investigation.

I may here add, however, a remark connected with this subject which is suggested by these salts of magnesia,—that substances certainly do appear to perform functions in reference to organic life which are entirely distinct from that of contributing the materials necessary to build up their substance. Thus magnesia exists largely in the mineral substance of the seeds on which man lives, and yet it is lime and not magnesia that enters into the composition of his bones, and which is found most abundantly in the other solid parts of his body, and even in his blood. We have every reason to believe that the magnesia of the grain does perform an important function in the animal body, and, in fact, is caused to collect in the grain with a view to that function. But this function is not to add to, or to remain in conspicuous proportion in any part of the body;

it must, therefore, be a more purely chemical function than those substances perform, which, like lime, contribute to the masonry of the system.

And what thus appears to be true of animals may also be true of plants. Substances may enter into them to perform purely chemical functions, without contributing largely to, or being found to form any considerable part of the fixed substance of the plant.

If this be so, we cannot judge from the composition of the ash as to the value or desirableness of a given substance, simple or compound, to a given plant. We must not, therefore, attach too much weight to inferences such as I have drawn above (*b*) as to the probable special adaptation of this sulphate of magnesia to crops of corn. We are rather to inquire, by repeated and careful experiment, whether such inferences are supported or confuted by experiment. In fact, among the higher uses of field experiment are those of testing, not only purely speculative opinions, but the soundness and justness, also, of those deductions to which chemical analyses of various kinds appear naturally and fairly to lead.

§ 6.—*Suggestions for experiments with sulphate of magnesia.*

1°. The practical man will find nothing very decisive in the two preceding sections, as to the money value of sulphate of magnesia, when applied alone to his usually cultivated crops. As a top-dressing to corn crops it has done good, and the presence of so much magnesia in grain may afford encouragement even to the practical farmer to apply it in spring to wheat, oats, and rye, with the hope of profit.

Upon potatoes, also, it appears to have done good, both as a top-dressing and as a mixture with the manure, and further trials may safely be made with it.

2°. To the scientific agriculturist, I would recommend—

a The trial of this, compared with the other sulphates, as described when treating of experiments with gypsum in a preceding section.

b The comparative action of the sulphate of magnesia, upon different crops—corn, pulse, hay, and roots. Is the extent of

its beneficial action at all proportioned to the quantity of magnesia contained in a crop? Has it any special action upon crops, such as mangel-wurtzel, in which there is comparatively little magnesia? What is its effect on the quantity, quality, and general appearance of different crops?

c Its special action, compared with that of gypsum, with the view of ascertaining if the one is more favourable to those which contain much lime, the other to those which contain less.

d Its action, compared with those of chloride of magnesium—magnesia dissolved in muriatic acid—nitrate of magnesia, carbonate of magnesia, and sulphuric acid. This series of experiments would have for its object to ascertain whether this salt exercises any special action as *sulphate* of magnesia, unlike or different from that exercised by its acid, or its magnesia, when presented to the plant in any other form. I attach much weight to the determination of this point, though it is not easy to chalk out such a line of experiment as shall clearly and indisputably lead to satisfactory conclusions.

e Comparative trials with different quantities of the salt, from 1 to 4 cwt. per acre, applied at different periods in the autumn and spring—all at once, or in successive portions at successive periods—with the seed, or as top-dressing in spring—and in the case of root crops with the manure or after the crop is above the ground.

f In making such experiments with sulphate of magnesia, regard must be had, as in the case of gypsum, to the quantity of magnesia which may be naturally present in the soil. This, as I have already shown, (p. 19,) will depend very much upon the geological formation of the district in which the experiments are undertaken.

§ 7.—*Suggestions for experiments with sulphate of iron.*

Sprengel had stated that sulphate of iron, when applied as a top-dressing to grass land in small doses, was productive of good effects. Recent experiments in France have confirmed this statement. It is said to impart greater vigour and a more healthy appearance to the crop, though exact numerical results

have not been published.* The same salt has also been tried by Mr Griss, as an application to diseased potatoes, and by Mr Gandry, to diseased fruit-trees; and in both cases, it is said, with decided success.

This salt, when exposed to the air, either in the state of crystals or of solution in water, is decomposed, becomes covered with a yellow ochre, and acquires acid properties. It may be doubted, therefore, whether the iron it contains, though to a certain extent necessary to the plant, exercises any real influence upon its growth. It is worthy of experimental investigation, however,—

1°. What is the effect of this sulphate compared with that of an equivalent quantity of sulphuric acid?—(See above, chap. vi. § 2.)

2°. What is its effect on the appearance and produce of plants compared with those of the sulphates of soda and magnesia, which are equally soluble in water?

3°. What are its special effects on different plants, when applied at different seasons?

4°. Has it any beneficial action upon sickly or diseased plants, when applied either as a top-dressing or in a state of solution to the roots?

It will be safer to commence with applications not exceeding 1 cwt. to the imperial acre.

* An account of the French experiments appeared in the *Annales de Chem. et de Phys.*, but as I omitted to note down the reference, I am at present unable to discover in what volume they are to be found.

CHAPTER VIII.

Experiments with the chlorides of potassium and with common salt, or chloride of sodium. Composition and general properties of the chlorides of potassium, sodium, calcium and magnesium, of the fluoride of calcium, and of muriatic acid. Suggestions for comparative experiments with the chloride of potassium applied alone. Results of experiments with common salt applied alone. Influence of circumstances upon the observed effects of common salt when applied directly to the land. Theory of the action of common salt when applied alone.

§ 1.—*Composition and general properties of the chlorides of potassium, sodium, (common salt,) calcium, and magnesium, of the fluoride of calcium, and of muriatic acid.*

The substances above named contain their several elements in the proportions represented in the following table:—

Name.	Consists of, in 100 parts—			
Chloride of potassium,	Chlorine	47.47	Potassium	52.53
... sodium,	...	60.34	Sodium	39.66
... calcium,	...	63.36	Calcium	36.64
... magnesium,	...	73.65	Magnesium	26.35
Fluoride of calcium, (fluor spar,)	Fluorine	47.73	Calcium	52.27
Muriatic acid,	Chlorine	97.26	Hydrogen	2.74

The substances called potassium, sodium, calcium, and magnesium, in the above table, are metals, white, soft, very light, and having a bright silvery lustre when newly cut with a knife. They speedily tarnish in the air, however, by combining with the oxygen of the atmosphere, and forming respectively the compounds known by the names of potash, soda, lime, and magnesia.

1°. *Chloride of potassium* is a white salt, which crystallises in cubes; is without smell; has a saline taste, resembling that of common salt; undergoes no change in the air; crackles when

thrown into the fire; and dissolves in less than 3 times (2.85 times) its weight of water at 60° F., and in less than twice its weight of boiling water. When dissolved in four times its weight of water, it lowers the temperature of the water by 20½° F.

This chloride exists in small quantity in sea water and in salt springs. That which is met with in commerce is for the most part obtained from kelp, and is employed in the manufacture of alum.

2°. *Chloride of sodium*, or common salt, is a white saline substance, which crystallises in cubes, is without smell, has an agreeable saline taste, and crackles or decrepitates when thrown into the fire. In these respects it agrees with the chloride of potassium; but it differs from it in the following properties:—

a In its ordinary or commercial form, it becomes moist in a damp atmosphere more readily than chloride of potassium.

b It dissolves in less than three times (2.78 times) its weight of water at 60° F., but boiling water does not sensibly dissolve more of it than water at 60° does.

c When dissolved in four times its weight of water, it only lowers the temperature of the water 3½ (3.4) degrees, instead of 20½, the reduction produced by the chloride of potassium.

3°. *Chloride of calcium* is obtained by dissolving lime in muriatic acid, and evaporating the solution to dryness. It is colourless, and without smell, but has a disagreeable bitterish taste. It attracts water from the air very rapidly, and runs to a liquid, or deliquesces. It is also exceedingly soluble in cold water. It occurs as a refuse in several manufacturing processes.

4°. *Chloride of magnesium* is obtained by dissolving magnesia in muriatic acid, and evaporating the solution to dryness; but it exists largely in the mother liquor of the salt pans, and from that cheap source it is usually obtained for manufacturing and other purposes. It is a white substance, void of smell, but has a disagreeable bitter taste. It is also very deliquescent, and very soluble in water. In all these respects it has much resemblance to the chloride of calcium.

5°. *Fluoride of calcium*, or fluor spar, is a substance well known to mineral collectors, from the beautiful cubical and octohedral crystals which it forms, of various colours. To the chemist it is interesting as the source of the hydro-fluoric acid—a substance which, from its property of corroding or etching glass, and of acting powerfully upon nearly all other bodies, is one of the most remarkable compounds with which we are acquainted. Fluor spar is easily reduced to the state of a fine, generally white powder. Though not absolutely insoluble in water, it is very sparingly so at any temperature.

In some of our lead-mining districts, it occurs in considerable quantity as a mineral production; and as sensible proportions of it are contained in the teeth and bones of animals, it must be present also in plants, and everywhere, in minute quantity, distributed through the soil.

6°. *Muriatic acid* is an acid gas which is produced, and rises in white vapours into the air, when sulphuric acid (oil of vitriol) is poured upon common salt. It has a strong affinity for water, which absorbs about 400 times its bulk of the gas. The liquid acid solution thus obtained is the common muriatic acid, or spirit of salt, of the shops. When the water is saturated, it contains 40 per cent (40.66) of the dry acid gas; but the acid of the shops is very variable in strength, and often contains as little as 20 per cent of dry acid. In the succeeding chapter, when recommending experiments with this acid, I shall describe a simple method of ascertaining its strength.

§ 2.—*Suggestions for comparative experiments with the chloride of potassium applied alone.*

I am not aware of any experiments having been made with chloride of potassium applied alone. The refuse of certain soap-works contains this salt, mixed with gypsum and various other substances, and this mixture has often been applied as a manure with profitable results. But such trials throw no light upon the special action of this compound on growing plants, nor upon the variations in that action which exhibit themselves in different soils and in the case of different plants. In the service both of physiology and of agriculture, it is to be wished

that careful experiments should be made. I would suggest, therefore—

1°. Experiments with chloride of potassium, applied at the rate of 2 cwt. per imperial acre upon corn crops, upon grasses and clovers, and upon crops of turnips, beet, potatoes, and cabbage. To the corn and grass crops it should be applied as a top-dressing in spring—for the roots it may either be covered in along with the manure in the rows, or it may be strewed with the hand around the plants after they have come up and have been thinned, as in this country is usually done with turnips, carrots, beet, and mangel-wurtzel.

2°. With the same chloride applied to the same crop, at the rate of 1 cwt., 1½ cwt., 2 cwt., and in the case of mangel-wurtzel and beet, turnips and cabbage, of 3 cwt. per acre.

3°. With the same quantity of 1½ or 2 cwt., applied at different seasons, and in different ways, to the same crop.

4°. The same experiments may be tried upon crops of different kinds. At one season, or month, or period of growth, it may be more favourable to one kind of plant than to another—to one more useful when applied all at once, to another in successive portions at successive periods, and so on.

5°. Its effect, compared with equivalent weights of sulphate of potash, and of carbonate of potash, (pearl ash,) on the same plant.

6°. The same tried on different kinds of plants.

If it is only the potash that acts in the case of all these compounds, then all ought to produce nearly equal, or at least very analogous effects. If the acid or the chlorine in any case modify the action, this influence ought to appear in the result. It may also appear that such special influence, if it exist, is different in the case of one plant from what it is in that of another.

7°. On different kinds of soils.

It is worthy of attention, whether the physical character or the chemical composition of the soil, and especially the proportion of lime it contains, does or does not affect the kind of influence this chloride is found to exercise.

8°. It will be physiologically interesting also to investigate by experiment the special action of the chloride of potassium upon marine plants. Will salt-loving plants thrive under the

influence of this chloride as well as they do under that of common salt? Can potassium perform the functions of sodium, or can the compounds of the two take the place of each other? This is not so much an inquiry for the practical man; it is one, however, upon which the man of science, who has the opportunity, might exercise himself, with the conviction that he was adding to that stock of useful facts and deductions on which the most profitable practice of agriculture is based.

§ 3.—*Results of experiments with common salt applied alone.*

Common salt has been applied to the land in various ways, for various purposes, and with various degrees of success.

It has been used alone, dug or ploughed into the land, harrowed in with the seed, and laid on as a top-dressing on grass, on young corn, and on root crops. It is mixed with the manure in the fold-yard or with the compost heap, is sprinkled upon the manure when it is spread in the drills, is used in a state of mixture with other saline substances, or is applied along with quicklime.

Among the purposes for which it has been used are those of killing weeds, the seeds of weeds, and insects injurious to crops, of increasing the quantity of grain and root crops, of improving their quality, and of adding weight to the grain, and strength to the straw, especially of wheat.

From the numerical results of successful trials as to its effects, which have been published from time to time, I select the following:—

Kind of Crop.	When made.	By whom.	Salt applied per acre.	Produce.	
				Unsalted.	Salted.
Wheat, . .	Before 1820.	G. Sinclair.	11 bush.	16½ bush.	22½ bush.
...	...	...	6½ ,,	11⅛ ,,	21 ,,
...	?	C. Johnson, Essex.	5 ,,	13½ ,,	26¼ ,,
...	1841.	Mr Fleming, Renfrew.	128 lb.	25 ,,	32 ,,
Barley, . .	?	Mr Ransom, Suffolk.	16 bush.	30 ,,	51 ,,
Oats, . . .	1844.	Mr Fleming, Renfrew.	3 cwt.	51 ,,	53 ,,

On globe turnips, in addition to farm-yard manure, Mr Maclean of Braidwood, Mid-Lothian, obtained in 1843 the following results:—

a Farm-yard manure, 30 carts produced		9 tons 17 cwt. of bulbs.
... ... 15 carts, Common salt, 4 cwt.		12 ... 12 ...
Increase,	.	2 tons 15 cwt.
b Farm-yard manure, 30 carts,	.	19 tons 4 cwt.
Do. 30 carts with 4 cwt. of salt,	.	25 ... 4 ...*
Increase,	.	6 tons 0 cwt.

Notwithstanding that so much has been said and written as to the use of salt, it appears to me surprising that so very small a number of experiments upon its effects, conducted with the requisite care and accuracy in regard to weights and measures, should be found recorded in our standard agricultural treatises and journals.

§ 4.—*Influence of circumstances upon the visible effects of common salt when applied directly to the land.*

A very slight consideration will show that local and other circumstances must have a very powerful influence upon the effects which common salt, applied alone, appears to produce upon our crops. Thus—

1°. *The neighbourhood of the sea* is likely to interfere with its action. Winds from the sea, and especially stormy winds, bear particles of salt water with them; and, in our island, rain seldom falls anywhere in which a sensible quantity of common salt cannot be detected. If the supply thus received from natural sources be sufficient, little benefit is to be expected from any new additions made by the cultivator. A range of hills sheltering a district from the sea, or an inland situation, may account for a more favourable result than is obtained in insular, exposed, and sea-side tracts of country.

2°. *The neighbourhood of a large town*, and the use of town manure, may also render the direct application of salt unprofit-

* *Transactions of the Highland and Agricultural Society*, July 1843, p. 34.

able. It has been ascertained that in this country, on an average, each person consumes about 14 lb. of salt every year. A large portion of this must find its way into the refuse of towns; and though much of it is emptied into the common sewers, and thence into the rivers, and so is sent back to the sea, yet a considerable proportion of it must be conveyed with the solid manure to the adjoining land. This may be enough to explain why the farmer of such land should, upon trial, derive no money benefit from the direct application of salt.

3°. *The geological structure of the country.*—The presence of marine formations, or of deposits of salt, or the occurrence of salt springs, may also render the addition of salt unprofitable.

4°. *The previous use of salt* upon the same land may render it unnecessary in after years. It has indeed, in some cases, been observed that the same land which gave a large profit upon its application one year, showed no improvement from its use in the next succeeding year.

5°. *The use of salt in feeding* may also render it unnecessary. Where the practice exists of salting hay, of giving salt to the stock, of leaving a piece of rock-salt in the feeding trough for the cattle or sheep to lick, the manure which is made must contain much salt. This will be in great part carried to the land, and will thus supply more or less completely any natural deficiency of this substance which the soil may exhibit.

6°. *The climate and season* will materially interfere with its action. In dry climates, where seasonable rains seldom fall, salt will rarely do anything but injury. In such climates the saline matter, natural to the soil, is brought to the surface by the waters which rise from beneath, and accumulates there so as often to be a chief cause of the destruction of the crops or natural herbage. An unusually dry season in our own climate has a similar effect. Thus in 1844, which was an unusually warm and dry summer, Mr John Wilson of Penicuick, in Mid-Lothian, applied salt to the grass he cut for hay in two fields, with the following results compared with nitrate of soda and saltpetre:—

		Per imp. acre. 1°	2°
a Nothing,	gave	144 stones.	96 stones
Common salt,	5 cwt.	144 ...	96 ...
Nitrate of soda,	2 ...	268 ...	208 ...
Nitrate of potash,	1½ ...	240 ...	192 ...

And upon these results Mr Wilson remarks, "I may state in regard to common salt, that although it has failed this season, 1844, I had previously used it to great advantage. In 1843 it increased the hay crop nearly one-third; and I presume it was owing to the dryness of the season that it had no effect on the first cutting, as the grasses appeared stinted in their growth after it was applied, and only partially recovered, and as the second crop was evidently benefited by it."*

He does not say whether he applied it in 1843 to the same piece of land; if so, the first dose of 5 cwt. per acre might have been enough for the two succeeding years. Supposing that Mr Wilson is right, however, in attributing the want of effect to the drought, it is interesting to remark how much less effect the drought had upon the nitrates. Indeed, it is not improbable that the beneficial influence of these nitrates, supposing them to have once been dissolved and absorbed by the soil, would be promoted and increased by a continuance of warm and dry weather.

7°. *The kind of crop*, whether it be a corn or a root crop, must materially influence the visible effects produced by common salt. All crops contain a certain proportion of common salt, and in green and root crops especially it appears to abound. The quantity found even in the same kind of plant is by no means constant; but it has been estimated by Mr Way, (*Roy. Ag. Journal*, viii., p. 186,) that turnips contain, according to the average of his trials, about two pounds in every ton of bulbs and mangel-wurtzel or beet, six pounds and a-half of common salt. It is deserving of rigorous experimental inquiry, therefore, whether these crops are generally grateful for supplies of salt, and whether they are so in the relative proportions in which, according to Mr Way, common salt is found in them.

* *Transactions of the Highland Society*, Oct. 1848, p. 142.

§ 5.—*Theory of the action of common salt when applied alone.*

There are certain known facts which appear to throw a tolerably clear light on the theory of the action of common salt, and, therefore, on the purposes for which it ought to be added to the soil. Thus—

1°. All plants contain chlorine in greater or less proportions, and the larger number, as I have already stated, contain it also in combination with sodium, forming chloride of sodium or common salt. One function of salt in the soil, therefore, is to enter the plant, and to supply it with the chlorine and the common salt which are necessary to its constitution.

2°. The leaves of plants, according to Sprengèl and Meyen, occasionally give off chlorine, but chiefly in the dark. This must arise from a decomposition of common salt, or of some other chloride. Another function of common salt, therefore, probably is, after having entered the plant, to give off its chlorine, and thus to yield soda, either to combine with the organic acids produced in the sap, or to perform other purposes, chemical and physiological, which may be necessary to the healthy growth of the plant.

3°. When common salt is present in a soil which at the same time contains a sensible quantity of carbonate of lime, it undergoes a slow decomposition, and carbonate of soda is gradually produced, (Berthollet.) This carbonate of soda has the property of combining with silica, and of rendering it soluble in water. It unites also with various organic and other substances present in the soil, which are known or believed to be necessary to the growth of plants.

4°. It is the result of trials in the field that common salt strengthens the straw of wheat in certain soils, giving it a smoother, brighter, and harder *skin*. In other soils this result follows more surely from the use of salt and quicklime mixed together.

Two other functions, therefore, may be performed by the carbonate of soda, which is produced when common salt and lime are together present in the soil. It may enter directly into the plant, and thus supply it with the soda it requires, or

it may dissolve silica, phosphoric acid, organic substances, &c., and carry them, or enable them more readily and abundantly to enter, into the plant.

If analysis shall satisfactorily prove, what many have taken for granted, that bright, strong straw always contains a larger quantity of silica than such as is soft and weak, then it may be considered as in some measure established, that when common salt is found to strengthen the straw, it does in reality dissolve silica in the soil, or in the compost heaps to which it is added, and carry it into the plant.

The above are nearly all the functions we are at present able distinctly to assign to common salt in reference to healthy vegetation. Whether as a compound body—chloride of sodium—it performs, in reference to the plant as distinguished from the soil, any other important office than that of conveying both its constituents into the sap without injury to the parts of the plant, is a point in reference to which I am acquainted with no facts that enable us as yet to form an opinion.

CHAPTER IX.

Experiments with common salt, *continued*, and with the chloride of calcium and magnesium, with muriatic acid, and with the fluoride of calcium. Suggestions for comparative experiments with common salt, applied alone. Experiments with chloride of calcium and with muriatic acid, applied alone. Experiments with chloride of magnesium suggested. Experiments with the fluoride of calcium suggested.

§ 1.—*Suggestions for comparative experiments with common salt, applied alone.*

THE use of salt in *field* culture is not very extensively practised, even with us, among whom salt is so very low in price. The practical man may, however, expect to derive benefit from its use upon all crops in places remote from the sea and from large towns, and where he does not give much salt to his stock. Also, where his wheat is apt to lodge, salt alone, or lime and salt, may be of much use to him; and, in soils and districts favourable to mangel-wurtzel and other varieties of beet, it is deserving of trial for this crop. The salting of manure is another form in which profit may follow the employment of it; and, in these and various other ways, the rent-paying farmer may be encouraged to make experiments with a material which in our markets can be bought so cheaply.

But, to the scientific agriculturist, there are several series of field experiments which I would venture to suggest as deserving of his attention, and as likely to lead to useful results.

1°. The comparative effects of salt applied in the autumn and in the spring, at different periods and in different proportions. More than about two cwt. per acre cannot with safety be applied at once to the growing crop in spring; but three or four times that quantity applied broadcast in the autumn, before or even along with the seed, will not involve much risk of injury.

2°. Comparative experiments with the chlorides of potassium, sodium, (common salt,) and calcium, and with muriatic acid and the carbonate of soda.

The object of this series of experiments is to ascertain, in virtue of which of its ingredients, or whether in virtue of both, common salt has a given effect in given circumstances upon this or that crop. If the chlorine alone be influential, the muriatic acid applied alone should produce nearly a similar effect, (see the following section.) If the salt act only by yielding soda, the carbonate of soda should more easily and immediately produce similar effects; and if it act as a compound body, a chloride, then possibly the chlorides of potassium and calcium may exercise a like influence.

3°. The comparative effects of muriatic acid, carbonate of soda, and common salt, applied in equivalent proportions, to *different classes* of plants. I mention this as a separate series of experiments, because, with three substances only, they can be more easily made upon a number of different crops or different plants. The inquiry, as the reader will see, possesses much physiological interest in addition to that which attaches to the practical applications of which its results may be susceptible.

4°. Experiments on the alleged effect of salt in strengthening the straw of wheat and oats. Is it really so strengthened, made stiffer, more shining, and more wiry? Does this strengthening arise from the straw being restrained in its growth, and being, therefore, shorter and less in quantity? Or is the stem thicker and, therefore, stronger, or is its substance less cellular or spongy and more compact? In any of these ways the straw may be made stronger, as well as by the absorption and fixing in its substance of more silicious matter. The careful and minute observer may do much good by determining—

a Whether the strengthening really takes place.

b In what circumstances, or if in all?

c In what the strengthening consists.

5°. Does salt always add to the weight of the grain per bushel? This is stated to be the case very frequently, and especially in the case of oats. Thus, at Barochan, in Renfrewshire, the weight, per bushel, of salted and unsalted oats, barley, and

wheat is given, as follows, in some of Mr Fleming's published experiments:—

	1842.			1843.			1844.	
	Salt.	No salt.		Salt.	No salt.		Salt.	No salt.
Oats, . .	—	—	...	42½	42½	...	44	40½
Barley, . .	57	55	...	56	56	...	—	—
Wheat, . .	62½	61	...	—	—	...	—	—

From these results it appears that the effect is by no means constant. It is desirable to ascertain, therefore—by salting certain portions of the same corn-field, and leaving certain other portions unsalted—upon what circumstances the alleged increase of weight per bushel depends. For example, does it depend—

a Upon the kind of grain?

b Upon the physical nature or chemical composition of the soil?

c On the quantity of salt applied?

d On the period of the year when it is laid on?

e Would its action be aided or diminished by applying the salt in successive portions at successive periods?

I think this alleged increase of weight in the grain is quite consistent with the view I am inclined to take of the sensible effect of salt—that it tends to diminish growth, and to hasten the ripening, and make it more perfect within a given time. The produce may weigh more per bushel, either because the grains are less, or because, being equally large, they weigh more. In either case, they will be more compact and dense; but it will be not uninteresting to ascertain to which of these two immediate causes the increased weight is owing. It will determine, in some measure, whether the growth or development of vessels is merely retarded, and thus the grain made more solid; or whether more solid matter is actually deposited in each seed in the same time—the deposition of the substance in reality accelerated instead of being retarded by the action of the salt.

In either of these two ways it is clear also that the greater compactness of the straw, if it really *be* more compact, may be explained. Either the salt causes the plant to build a thinner wall, but to fill it up and make it more solid, or to make the

wall thicker and more solid at the same time. In either way, greater strength might be attained.*

There can be little doubt, I think, that a warmer summer will usually ripen grain more thoroughly, and make it more compact, harder, and heavier per bushel; but it does not follow from this that, in the same season, certain applications to the soil may not also increase the comparative compactness and weight.

6°. Does salt really promote the growth of the white beet and of mangel-wurtzel more than the turnip? We have seen that the former, according to our present analyses,† contains more salt than the latter. Will its application to these and other crops be beneficial in proportion to the quantity of soda or common salt they respectively contain?

7°. A similar question applies to the carrot—founded on a principle already explained in this work, p. 16,—its alliance, like the beet, to species found wild near the sea. Will salt be peculiarly grateful to this plant? Or will it cause such plants as the Tussac grass to grow healthily in inland situations?

Will an application of salt to such plants compensate for the neighbourhood of the sea?

The adjustment of series of experiments—always duplicate, at least, and always capable of being compared with portions of the same crop to which no application has been made—this adjustment is so simple, and there is so much room for variation, that I do not present any schemes for the guidance of experimenters. I may only express my hope that some of the topics above suggested may be taken up and submitted to rigorous field investigation.

* Mr Lawes considers the weight of the bushel to be determined by the temperature. The hottest year, 1846, gave him the greatest weight per bushel; the coldest year, 1845, the smallest weight per bushel. In 1846, the bushel of the unmanured space weighed 63¼ lb.; of the highly manured space, 62¾ lb.: the average of 36 experiments was 63 lb. In 1845, the bushel of the unmanured space weighed 56½ lb.; of the most highly manured, 57 lb.: the average of the whole being 56¾ lb.

† See section 4 of the preceding chapter, p. 146.

§ 2.—*Experiments with chloride of calcium and with muriatic acid applied alone.*

1°. *Chloride of calcium.*—This salt—which in some of our manufactories is now produced in large quantities, and, for want of a market, usually runs off in a liquid form to the nearest stream—has been recommended for fixing the ammonia which escapes during the fermentation of manure-heaps, and also for experimental application to various crops.

As early as 1824, it was recommended in France by Dubuc and by Lemaire Lisancourt,* as doubling and tripling the size of plants, and causing the production of much larger fruits and tubers. They dissolved it in about 60 parts of water, and applied it at two successive periods, with considerable intervals: in the case of grain and root crops, once before the crop was put into the ground, and again after it had come up. In this way it was applied with success to potatoes, turnips, maize, the poppy, and to fruit-trees.

The only experiments having any claims to precision, however, with which I am acquainted, are those of Kuhlmann, and they are by no means encouraging. He applied it to the same portion of old grass-land in 1844 and 1846, omitting 1845, in which year no application was made.

The following were his results, in kilogrammes per hectare, for each of the three years:—

	1844.		1845.		1846.	Total
	1st cut.	2d cut.	1st cut.	2d cut.		kilos.
No application,	2427	1393	2779	1707	3330	11,636
Chloride of calcium, 220 lb. per acre each year,	2417	1413	2287	1823	3036	10,976
Total difference in three years,						660†

The crop of hay in the first year was increased by 10 kilogrammes. It therefore did no harm on the first application. In each of the other years, however, there was a diminution

* *An. de Chem. et de Phys.*, xxv., p. 214, or xxvi., p. 214.

† I have not reduced these quantities to pounds and acres, as it is only the comparative results that interest us. A hectare, however, is about 2½ acres imperial, and a kilogramme about 2¼ lb.

amounting, on the whole, to 660 kilogrammes, or about 6 per cent. This diminution, however, is so small, that, had there been duplicate or triplicate experiments to determine the limits of natural variation, it might have disappeared altogether.

Rigorous comparative experiments, therefore, with this substance are still required, applying it,—

a In different proportions of 1, $1\frac{1}{2}$, and 2 cwt. per acre.

b At different and successive periods.

c To different crops,—not only to herbage and young corn, but to root-crops, and to fruit-trees. In France it was said to have increased potatoes and onions to two or three times their usual size; it is deserving of trial, therefore, upon these crops. To fruit-trees it must be applied in the liquid form, and it might not be less advantageous if tried upon other plants also in a state of solution.

Comparative experiments with other chlorides are also to be recommended similar to those I have described when treating of common salt, (p. 150.)

2°. *Muriatic acid.* The muriatic acid, or spirit of salt of the shops, has not been much tried in agricultural experiments. It has been most frequently used in dissolving bones, though for this purpose sulphuric acid is now generally preferred.

The only numerical results obtained by the use of this acid which I have met with, are given by Mr Tinzmann, whose experiments with sulphuric acid are quoted in a preceding chapter. In 1841 he applied it to clover, at the rate of 7 lb. per imperial acre, in different states of dilution, with the following effects upon the quantities of hay and seed yielded by the Prussian morgen:—

		Hay.	Seed.
No application,	. .	11 cwt. 30 lb.	$2\frac{1}{2}$ bushels.
Muriatic acid with	100 water,	12 ... 30 ...	$2\frac{1}{8}$ ...
...	200 ...	12 ... 30 ...	$2\frac{3}{4}$ ...
...	500 ...	13 ... 10 ...	$1\frac{7}{8}$ ...
...	1000 ...	15 ... 60 ...	$2\frac{3}{8}$ ...

The after barley crop in 1824 from the five portions was 7, $10\frac{1}{2}$, $9\frac{7}{8}$, $9\frac{1}{8}$, and 7 bushels respectively.

The quantity of acid employed in these experiments was too

small to justify us in placing much confidence in Mr Tinzmann's results, especially as we have no duplicate experiments, and no results obtained by the application of water alone with which to compare them. Still the reader will see that experiments with the acid may be safely made.

I would recommend, therefore, that such experiments should be repeated, upon different crops, and that the acid should be applied in different quantities, at different times, and in different states of dilution. Especially, I would suggest, the comparative experiments with common salt and other chlorides already described in a preceding section.

The muriatic acid of the shops varies much in strength. It contains from 20 to nearly 40 per cent of pure acid. The simplest way of approximating to the equivalent weight of the acid, is to add to it the common soda of the shops, or common chalk, little by little, till it ceases to have the slightest acid taste; the quantity of acid which requires 180 of soda, or 63 of chalk, to produce this effect, is the quantity to be employed against 73 of common salt, 70 of chloride of calcium, and so on.—(See table of equivalent quantities, chap. v. § 8, p. 99.)

§ 3.—*Experiments with chloride of magnesium suggested.*

No experiments, that I know of, have yet been made with chloride of magnesium applied alone. As a refuse of our salt-works it can easily be obtained, and, by solution in the smallest possible quantity of water, may be in a great measure freed from the gypsum and common salt with which, in the mother liquor of the salt-pans, it is usually mixed. It should be tried—

1°. Alone, in different proportions, (½, 1, 1½, &c. cwt. per acre,) applied at different and successive periods, and upon different crops. Potatoes and corn crops may be especially tried.

2°. In comparison with the other chlorides of which I have already spoken in this chapter, and especially with the chloride of calcium.

3°. In comparison with sulphate of magnesia, (Epsom salts.) If its action is beneficial upon any plant, it is desirable to ascertain if an equivalent quantity of magnesia in another state of combination will produce an equal or an analogous effect.

4°. In comparison with muriatic acid, and carbonate of magnesia, each applied alone, with the view of inquiring whether the effect it produces, if any, is due to the magnesia, or to the chlorine it contains, or is caused by some special property which the chloride as a compound possesses. Its great solubility is such a property; and it is not unlikely that this will alone cause its magnesia to act in the soil, and upon the plant, in a very different way from the nearly insoluble carbonate.

§ 4.—*Suggestions for experiments with the fluoride of calcium, (fluor spar.)*

Fluorine, or fluoride of calcium, has not been much sought for as yet in the ashes of plants, but it must exist there, since it is found in the proportion of from 2 to 4 per cent in the earthy part of the bones and teeth of animals. As the mineral fluoride can in some parts of the country be procured in considerable quantities, it would be interesting, therefore, to make experiments with it upon growing plants. Being very sparingly soluble in water, it may be applied with much safety. For the same reason it ought perhaps to be laid on the land, or around the seeds or roots of plants, in considerably larger doses than any of the soluble saline substances of which we have hitherto treated. It ought to be tried—

1°. Alone, applied in different proportions and to different plants.

2°. In comparison with an equivalent quantity of carbonate of lime—finely powdered chalk. This will show how far any effect can be ascribed to the fluorine which the fluoride contains.

3°. In comparison with sulphate of lime—common gypsum. It cannot well be tried against the chloride of calcium, because of the extreme solubility of the latter, and the greater ease therefore with which, as we may presume, the roots of plants will take it up. Indeed, it will be necessary first of all to know with some degree of correctness, what effect, if any, the fluoride does produce, before we can contrive further experiments by which that effect is likely to be tested and analysed.

CHAPTER X.

Experiments with the carbonates, phosphates, and silicates of potash and soda. Composition of the carbonates of potash and soda, their properties and their functions in the soil and in the plant. Results of published experiments with these carbonates. Suggestions for experiments with the carbonates of potash and soda. Composition of the phosphates of potash and soda. Results of experiments with the phosphate of soda. Suggestions for comparative experiments with these phosphates applied alone. Composition of the silicates of potash and soda, their properties and their functions in the soil, and in the plant. Results of past experiments with these silicates. Suggestions for future experiments with the silicates of potash and soda.

§ 1.—*Composition of the carbonates of potash and soda, their properties and their functions in the soil and in the plant.*

1°. Composition of the carbonates of potash and soda.

Carbonate of potash, (dry pearl ash,)	consists of	Potash,	68.2
		Carbonic acid,	31.8
			100

Carbonate of soda (crystallised, or common soda of the shops,)	consists of	Soda,	21.8
		Carbonic acid,	15.4
		Water,	62.8
			100

Carbonate of soda (dry or pure soda ash,)	consists of	Soda,	58.7
		Carbonic acid,	41.3
			100

2°. Properties of these carbonates.

a The carbonate of potash, or pearl ash, attracts moisture rapidly from the air, and deliquesces or runs to a liquid. It has an acrid, alkaline taste, and dissolves in less than its own weight of water at 60° F.

b The carbonate of soda of the shops effloresces, or falls to a dry white powder, when exposed to the air at ordinary temperatures. This is owing to its giving off water, instead of attracting it from the air as carbonate of potash does. It has a disagreeable alkaline taste, and dissolves in twice its weight of cold, and in less than its own weight of boiling water.

These two carbonates possess in common the property of dissolving vegetable matter in the soil, and of disposing it to decompose and become soluble in water. They also dissolve silica, decompose mineral substances, and dispose the sulphur of the soil* to form sulphuric acid, and combine with them. They thus form soluble sulphates, silicates, &c., which they convey into the plant.

3°. Functions of these carbonates.

Thus their functions may be said to be fourfold,—

First, To dispose certain other substances to undergo peculiar chemical changes in the soil.

Second, To convey these substances—organic acids, sulphuric acid, silica, &c.—from the soil into the plant. Under this head it ought particularly to be noticed, that though solutions of these carbonates do not dissolve lime and magnesia directly, yet that, when they have previously dissolved a portion of the ulmic or humic acid of the soil, they have the power of taking up sensible quantities of lime and magnesia also, and of thus fitting them for entering into the roots of the plant.

Third, To supply directly the potash and soda which the plant requires to form or modify its substance.

Fourth, To perform, promote, or aid in the production of those chemical changes which are continually going on in the interior of the plant, and which are necessary to its growth.

In regard to the functions which the two carbonates are capable of performing in the soil, there is reason to believe that they may take the place of each other without inconvenience to the plant—that it is a matter of comparative indifference, therefore, whether we apply the one or the other to the soil. How far this is the case with the functions they respectively

* That contained in the sulphuret of iron of the soil, for example, which, slowly combining with the oxygen of the air, forms sulphuric acid.

perform in the interior of the plant, does not yet appear. In plants which grow at a distance from the sea, the relative proportions of the soda and the potash differ very much, but generally the potash is present in much the larger quantity. This would seem to imply that the functions of the potash cannot be altogether performed by the soda. But the question is one that is far from being solved, and in regard to which carefully conducted experimental inquiries would be likely to lead to practically useful as well as physiologically interesting results.

§ 2.—*Results of published experiments with the carbonates of potash and soda.*

The number of published experiments made with these carbonates is very small. The following are all with which I am acquainted:—

1°. On wheat, Taunton-dean variety, at Whitehill, Mid-Lothian, by Mr Main. Top-dressed 30th July 1847.*

	Grain.	Straw.
Nothing gave . .	27½ bushels and	19¼ cwt.
Carbonate of soda, 2 cwt.,	29½ ...	23¼ ...
Increase,	2 bush.	4 cwt.

2°. *On oats* sown on old lea, trenched with the spade, by Mr Fleming of Barochan, in Renfrewshire, in 1844:—†

	Grain.	Straw.	Weight per bush.
Nothing (average of four portions) gave	51 bush.	31 cwt.	40½ lb.
Carbonate of soda, 2 cwt., . .	53 ...	30¾ ...	43 ...
Increase,	2 bush.	—	3 lb.

3°. *On oats* after turnips, by Mr Main, at Whitehill, in 1846:—‡

	Grain.	Straw.
Nothing gave	45 bush.	24 cwt.
Carbonate of soda, 2 cwt., .	49 ...	21½ ...
Carbonate of potash, (pearl ash,) 2 cwt.,	58¾ ...	23¾ ...

In none of these experiments did the carbonate of soda pro-

* *Transactions of the Highland Society,* March 1849, p. 530.
† Ibid. March 1845, p. 410. ‡ Ibid. January 1848, p. 177.

duce any marked effect. The slight increase in each case might either have disappeared altogether, or have appeared greater had duplicate experiments been tried in each case.

The absence of such duplicate experiments also renders less satisfactory the large increase shown in the last experiment upon oats, in which the comparative effects of *equal weights* of carbonate of soda and carbonate of potash were observed under the same circumstances. The result, however, is sufficiently favourable to justify the repetition of the experiment, with the greater accuracy which our present experience enables us to attain.

But, in regard to the comparative effects of these two carbonates, as shown by Mr Main's experiment upon oats, this important remark is to be made, that the application of equal weights of the two substances by no means tests their relative efficiency upon any crop, or in any circumstances.

Carbonate of soda, as we have seen in the preceding section, contains 62 per cent of water, and only 22 per cent of soda, while pearl ash contains naturally no water, and 68 per cent of potash. But the pearl ash of commerce is usually more or less moist. Suppose it, therefore, to have contained even as much as 20 per cent of water, the respective quantities of the dry carbonates applied in the two hundredweights of each salt were as follows:—

Dry carbonate of soda, ...	85 lb.
Dry carbonate of potash, ...	179 lb.

The experiment merely says, therefore, that 85 lb. of carbonate of soda do not produce an equal effect with 179 lb. of carbonate of potash. Now, according to the table of equivalent quantities given in a preceding chapter,* 87 pounds of dry carbonate of potash ought to produce an equal chemical effect with 67 of dry, or 179 of crystallised carbonate of soda; therefore, the 179 lb. of the former which were applied in this experiment are equal in chemical effect to 370 lb. of crystallised carbonate of soda, while only 224 lb. were employed. Thus the experiment of Mr Main does not necessarily indicate a more favourable or more powerful action on the part of the potash

* Chapter V., § 8, p. 99.

salt. It not only leaves the subject perfectly open, but encourages us to further experiments.

According to Lampadius, potash or wood-ashes aid the growth of corn after turnips or potatoes; according to Sprengel, carbonate of soda, in a remarkable manner, assists the growth of buck-wheat; while, according to Mr Fleming, they all greatly hasten the growth and increase the produce of strawberries and other garden fruits. These statements suggest and hold out further inducements to experimental trials.

§ 3.—*Suggestions for experiments with the carbonates of potash and soda.*

Repeating the statement of the preceding section, that 87 lb. of dry* carbonate of potash are equivalent to and ought to be tried in comparison with 179 of crystallised carbonate of soda, I would suggest,—

1°. Accurate experiments with each of the carbonates made in duplicate. They may be applied as top-dressings either to wheat, oats, barley, rye, or buck-wheat.

2°. As our green crops contain a larger proportion of alkaline than of other mineral matter, their comparative action upon such crops should be specially investigated.

3°. Their action upon strawberries, gooseberries, and other garden fruits, is worthy of accurate estimation. On larger fruit-trees, similar trials may also be made.

4°. Their effects on each crop, when applied in different doses, all at once, or in successive portions, and at different seasons. This investigation alone involves a widely extended series of experiments.

5°. The comparative action of the two carbonates on different crops, applied under the same circumstances, and in *equivalent* proportions. These experiments will not only solve the practical question, whether the low-priced carbonate of soda can be substituted for the high-priced carbonate of potash in artificial manures, but will throw light also on the chemico-physiological

* The quantity of water contained in the common pearl ash may be ascertained by heating an ounce of it in a hot oven, or on a hot plate, and determining the loss of weight.

questions as to the relation which potash and soda bear to the healthy life of the plant, and as to their power of taking the place of each other. This latter inquiry is one which is deserving of extended and special attention; and I shall have occasion to revert to it in a subsequent chapter.

6°. Their effects, in comparison with those of equivalent quantities of the sulphates of potash and soda, and of the chlorides of potassium and sodium. This series will determine whether they owe their influence upon the soil or the plant merely to the alkali they contain; or whether the special properties possessed by this alkali in its state of carbonate may not determine the nature and extent of its influence.

7°. Lastly, as these carbonates exercise a special action on the organic matter of the soil, in hastening its decomposition and rendering it soluble, I would suggest experiments as to their action on peaty soils—on dry moorish soils, rich in inert vegetable matter—and generally on soils called *deaf*, *sleepy*, *silly*, &c. On such soils lime very frequently produces beneficial effects, and I think it not unlikely that poor corn on such soils might be renovated by a top-dressing of these carbonates, applied in the early growing-time of spring.

§ 4.—*Composition of the phosphates of potash and soda.*

1°. *Phosphate of potash.* Two varieties of phosphate of potash are known. They consist respectively of—

a		b	
Potash,	56.94	Potash,	34.40
Phosphoric acid,	43.06	Phosphoric acid,	52.48
		Water,	13.12
	100		100

2°. The phosphate of soda of the shops consists of—

Soda,	17.88
Phosphoric acid,	20.40
Water,	61.72
	100

These phosphates are prepared by treating an excess of

burned bones with dilute sulphuric acid, separating the gypsum which forms, and then adding carbonate of potash or carbonate of soda, as long as the liquid has a sour taste, or reddens litmus. The clear solutions thus neutralised are concentrated by evaporation, and the phosphates separate in crystals when the liquid is set aside to cool.

If the solution, after being saturated with carbonate of potash, is evaporated to dryness, the first phosphate of potash, containing 43 of acid, is obtained. If it be only concentrated, and then set aside to cool, the second, containing 52 of phosphoric acid, is deposited in crystals.

All the three phosphates are permanent in the air, but dissolve readily in water. Only the soda salt is at present met with in the shops, and it is too high in price to be recommended to the farmer. Both, however, might be prepared in a less pure form at a comparatively cheap rate, should experience prove them to be possessed of fertilising properties, which are capable of being made a source of profit to the practical man.

The equivalent weights of the three salts are—

Phosphate of potash, (*a*)	207
... ... (*b*)	170
Phosphate of soda, ...	437

It is only with the first of these phosphates of potash that comparative experiments can be tried against the phosphate of soda. The relative atomic proportions of alkali and acid in the second phosphate of potash are different from those in the phosphate of soda, and therefore their chemical effects on the soil or on the plant will be different.

§ 5.—*Experiments with the phosphates of potash and soda applied alone, and along with super-phosphate of lime.*

1°. The only experiment with the phosphate of soda applied alone which I have met with has been published by Kuhlman. He applied it in 1844 to old grass land, to be cut for hay, in the proportion of 300 kilogrammes of the crystallised salt per hectare dissolved in 1000 litres of water. In 1845 no application was made, but in 1846 the same substance in the same

quantity was applied again. The following were the weights of hay yielded by the two plots during the three years :—

	1844.	1845.	1846.
Nothing gave . .	3820	4486	3330
Phosphate of soda .	4326	4657	3573
Increase, . .	506	171	243

An increase in each year was thus perceptible; but only in the first year can the differences be regarded as greater than the ordinary variations to be expected in different portions of the same field.

2°. Along with superphosphate of lime, both of the above phosphates were applied by Mr Lawes, in 1844, to his turnip-crop, at Rothampstead farm, Herts, with the following results:—

No manure, gave . . .	2 tons 4 cwt. of bulbs.
Farm-yard manure, 12 tons, .	10 ... 15 ... ...
Superphosphate of lime, 1 cwt., Phosphate of soda, 4 cwt.,	6 ... 13 ... ...
Superphosphate of lime, 1 cwt., Phosphate of potash, 4 cwt.,	6 ... 2 ... ...
Superphosphate of lime, 1 cwt., Phosphate of magnesia, 4 cwt.,	6 ... 13½ ... ... *

These experiments are insufficient to throw any light on the special action of the several phosphates employed. We have no experiment with the superphosphate applied alone at the rate of 1 cwt. per acre, and we have no trials in duplicate. The results appear to say that the effects of the three phosphates of potash, soda, and magnesia, applied in equal quantities, are sensibly alike, which can scarcely be the case under any ordinary circumstances of soil or crop.

§ 6.—*Suggestions for comparative experiments with the phosphates of potash and soda.*

As phosphoric acid is so necessary a food to plants, and as its compounds with potash and soda are very soluble, there is reason to believe that on certain soils, for certain crops, and applied at certain seasons of the plant's growth, they might

* *Journal of the Royal Society*, vol. viii. p. 510.

be used with much advantage. It is not impossible that they may even be found capable of profitable use by the practical farmer. I would, therefore, suggest that accurate comparative duplicate experiments should be made.

1°. With each of the phosphates of potash and soda upon different crops, and applied in different equivalent proportions.

2°. With the two phosphates tried against each other upon the same crop, under the same circumstances and in equivalent quantities.

3°. With each phosphate applied at different seasons, or at different periods of the plant's growth.

4°. With each phosphate in equivalent quantities divided into two or more portions, to be applied at successive periods.

5°. With each phosphate applied to soils of different qualities and composition. I would especially suggest such comparative trials on soils which abound in, and which are poor in lime respectively.

The results of these experiments will indicate what ought next to be done in the way of practical trials with these substances.

§ 7.—*Composition of the silicates of potash and soda, their properties and their functions in the soil and in the plant.*

1°. Composition of the silicates of potash and soda.

a Silicate of potash, prepared by melting one part by weight of carbonate of potash with three of silica, (pounded quartz, flint or silicious sand,) consists of about silica 82, and potash 18. Prepared by melting one of carbonate of potash with two of silica, it consists of about 75 of silica, and 25 of potash.

b Silicate of soda, prepared by melting together one part by weight of dry carbonate of soda with three of silica, consists of about 84 of silica, and 16 of soda. By fusing together one of dry carbonate of soda with two of silica, it consists of about 58 of silica and 22 of soda.

Both of these silicates, however, are liable to considerable variations in their composition as they are usually prepared with the view of being sold for agricultural purposes. They contain for the most part a larger proportion of soda or potash

than any of the salts here mentioned; and in so far as their use to plants is concerned, this increase of alkaline matter will probably be an advantage.

2°. *Properties.* There are only two properties of these silicates on which it is necessary here to insist.

a The special valuable property of the silicates of potash and soda is their solubility in water. Those which contain the largest quantity of alkali are most readily soluble, and are, therefore, most likely to exercise a beneficial action when applied to the land.

b These silicates are decomposed by the carbonic and by most other acids. Hence, in the soil, where carbonic acid is usually abundant, they are liable to be more or less completely decomposed, forming carbonates of potash and soda, and liberating the silica they contain. It is a property of silica so liberated, however, that it is to a certain extent soluble in pure water, and is thus able to enter directly into the roots of plants.

3°. *Functions.* The functions of these salts, in reference to the soil, therefore, may be either to supply it with the soluble silicates of potash or soda in which it may be deficient, or, if they are decomposed in the soil, with soluble silica, and with the carbonates of potash and soda. These carbonates, as I have already explained in a previous section of this chapter, are capable of performing important after functions in reference both to the soil and to the plant.

In the plant, the functions exercised by the silicates must be, *first*, to convey into the sap and thence to the exterior part of the stem, where it is usually deposited, the silica which it requires in a soluble form. *Second*, having deposited the silica in an insoluble state to supply alkaline matter to the sap, either as an agent in producing chemical changes necessary to the plant's growth, as a base to combine with the organic acids formed in it, or as a building material required for the completion of its several parts. It is probably the carbonic acid taken in by the leaf, or the other organic acids naturally formed in the sap, which decompose the silicate, and enable it to deposit the silica in a more or less insoluble form where the structure of the plant requires it.

§ 8.—*Results of experiments made with the silicates of potash and soda.*

Lampadius first observed that silicate of potash produced remarkable effects on Indian corn and on rye. It has since been supposed by many that, as our grasses and the straw of our grain plants contain so much silica, the artificial application of soluble silicates to such crops would be attended with much benefit. Especially by those who held that the function of silica in the straw was to give it strength, it was recommended to apply these silicates when the straw of wheat or of oats was apt to be laid. Mr Lawes, however, states, as the result of repeated experiments, that these silicates do no good to grain plants.*

Some years ago I showed,† *first*, that all our cultivated soils contain a sensible proportion of silica in a soluble state; *second*, that all our springs and streams of water contain an appreciable quantity of silica dissolved in them; and *third*, that the roots of plants had the power of taking up silica from the soil even when it contained nothing which strong acids could extract from it, and of conveying this silica into their sap. I hence inferred that, as a general rule, the artificial addition of soluble silicates to the soil was not necessary, though it might be useful, and was therefore deserving of trial by experiment.

Few accurate experiments, however, with these silicates, applied alone, have as yet been made and published. The following are all I have hitherto met with:—

1°. To oats grown upon moss land Mr Fleming of Barochan, in Renfrewshire, applied silicate of soda on the 29th of May 1845, with the following results per imperial acre:—

	Grain.	Straw.	Weight per bushel.
No application gave .	47 bushels	$30\frac{1}{4}$ cwt.	38 lb.
Silicate of soda (2 cwt.) gave	49 ...	$37\frac{1}{2}$ ...	39 ...

The growth of straw was here promoted, but the quantity of grain was not materially increased. He considered the straw to be stronger in this case, as well as in several other

* *Journal of the Royal Agricultural Society*, viii. p. 259.

† *Contributions to Scientific Agriculture*, pp. 50-56.

experiments made on the same field in which this silicate of soda was applied along with certain other substances.*

2°. To potatoes (early American) Mr Fleming applied it in 1842 mixed with the manure. The result was as follows:—

Manure (35 cwt.) gave . . .	8 tons	17½ cwt.
Manure and silicate of potash (1 cwt.) gave	15 ...	0
Increase, . . .	6 tons	2½ cwt. †

This increase was very large; but, supposing its correctness to be undoubted, it is by no means clear that the effect was due to the action of the substance *as a silicate*, and not merely to that of the carbonate of potash, which would be produced when the silicate was mixed with the manure.

§ 9.—*Suggestions for comparative experiments with the silicates of potash and soda.*

The remarks I have made in the preceding sections will have shown the reader that there are many interesting questions to be solved by rigorously accurate comparative experiments with these silicates. I would suggest trials, therefore, in reference to the following questions:—

1°. Do these silicates benefit crops generally? This will require experiments upon different crops with each of the silicates; and they may be tried in different proportions, applied at different periods of the plant's growth, and either all at once or in successive smaller applications.

2°. Do both of these silicates equally benefit the same crop? This suggests comparative experiments with the two silicates upon the same crop and under the same circumstances.

3°. Is their effect greatest upon those plants which contain much silica—the grasses and corn-crops, for example—or on those which, like cabbage and the root-crops, contain much alkaline matter? To solve this, comparative experiments must be made with each silicate upon these different classes of plants.

* *Transactions of the Highland Society*, July 1847, p. 34.

† See Appendix to my *Lectures on Agricultural Chemistry and Geology*, first edition, p. 63.

4°. Do they, in any material degree, alter the strength, appearance, or quality of the straw of the corn-crops? This question may be answered by the same series of experiments which is required for the solution of the first and third questions.

5°. Do they act as silicates, or only in virtue of the potash and soda they contain? This suggests comparative experiments with these silicates, and with the equivalent quantities of the carbonates of potash and soda, which will act in the soil and upon the plant in the same way as the alkaline matter of the silicates after they have been decomposed in the soil. They may also be tried against equivalent quantities of chloride of potassium and of common salt—the latter of which, as I have already stated, has been found to have a beneficial influence upon the appearance and strength of wheaten straw.

6°. Lastly, it is worthy of inquiry whether the composition of the soil, the nature of the burned lime applied to it, or the composition of the springs or streams that water it, have any influence in modifying the action of these silicates. This inquiry is less purely practical than the others, and demands more chemical skill; but it is deserving of the careful attention of those who possess at once the practical facilities and the chemical skill it requires.

CHAPTER XI.

Experiments with the nitrates of potash, soda, lime, and magnesia. Composition of the nitrates of potash, soda, lime, and magnesia—their properties and their functions in the soil and in the plant. Sensible effects produced by the application of the nitrates of potash and soda. Results of past experiments with the nitrates of potash, soda, and lime. Results of experiments with nitrate of soda applied in different proportions to the same crop. Suggestions for new experiments with the nitrates of potash, soda, lime, and magnesia.

§ 1.—*Composition of the nitrates of potash, soda, lime, and magnesia—their properties and their functions in the soil and in the plant.*

1°. COMPOSITION of the nitrates of potash, soda, lime, and magnesia.

a The nitrate of potash or saltpetre	consists of	potash, . .	46·6
		nitric acid, .	53·4
			100
b The nitrate of soda or cubic petre.	consists of	soda, . . .	36·7
		nitric acid, .	63·3
			100

Both salts, however, as they occur in commerce, are mixed with a variable proportion of impurity. Saltpetre contains about 5 per cent of chloride of potassium or of common salt, and nitrate of soda from 5 to 12, or even 20 per cent of common salt. The proportion of common salt in the latter may be roughly estimated by throwing a little of it on a red-hot plate, when, if it contain common salt, it will decrepitate or crackle; if not, it will quietly melt.

c The nitrates of lime and magnesia, when perfectly dry, consist respectively of—

	Nitrate of lime.			Nitrate of magnesia.
Lime, . . .	34·5	...	magnesia, .	27·6
Nitric acid, . .	65·5	...	nitric acid, .	72·4
	100			100

2°. Properties of these nitrates.

a Nitrate of potash, or saltpetre, is colourless and void of smell, but possesses a cooling saline taste. It crystallises in long striated six-sided prisms, which do not alter in the air. It dissolves in about four times its weight of water, at 60° F. Heated below redness, it melts into a colourless liquid: at a higher temperature, it is decomposed, giving off oxygen gas.* Thrown upon red-hot coals or charcoal, it causes a vivid combustion or deflagration; or if it be heated nearly to redness in a crucible, and a piece of charcoal or other organic matter be thrown into it, the latter burns away with a vivid combustion, and the nitrate is changed into *carbonate* of potash. This deflagrating property is common to all the nitrates. Saltpetre possesses a considerable antiseptic property, and hence its employment in the curing of meat.

b Nitrate of soda is also colourless and without smell, and has a cooling saline taste. It differs from saltpetre in crystallising in rhomboids like calc spar, instead of long prisms, in attracting moisture and deliquescing in moist air, and in requiring only twice its weight of water to dissolve it. When heated, it melts, decomposes, and deflagrates, as the nitrate of potash does.

c The nitrates of lime and magnesia differ from those of potash and soda in not readily crystallising, in being very deliquescent when exposed to the air, and in being very soluble in water. Like the other nitrates, they melt and deflagrate, and in many localities are naturally formed in the soil.

3°. Functions of these nitrates in the soil and in the plant.

Of the functions of these nitrates in the soil it is not easy to speak. They may supply oxygen to the organic and mineral matters of the soil, and thus promote their passage to a state of

* This oxygen is derived from the nitric acid, which consists, in a hundred parts, of 74 of oxygen and 26 of nitrogen.

combination more suited to the plant's growth. The nitrogen they contain may also enter into new states of combination; and such may be the case likewise with their potash, soda, lime, and magnesia, in the presence of the other mineral and vegetable matters with which they come in contact in the soil. But upon these points we have as yet very little light, and therefore I refrain from advancing any mere speculations.

Their function in the plant is probably threefold. First, to supply nitrogen, which we know to be so necessary a part of the substance of the plant. Second, to supply alkaline and earthy matters, which are also necessary to their formation. Third, to act chemically in the sap in producing or inducing those chemical changes, on the rapid succession of which the more speedy growth of plants depends.

In reference to this last kind of action, I throw out two suggestions which appear to me to have some weight. First, that the large proportion of oxygen which the nitrates contain, and the ease with which they yield it up, has something to do with their striking action upon vegetation. Second, that the constant presence of a large proportion of nitrogen at the extremities of the roots of plants—which nitrogen plays an important part in vegetable growth, and which the soluble nitrates when applied to, or naturally produced in the soil, are in a condition readily to supply—is connected with the *immediate* nature of the effect they are seen to produce. No sooner do they enter into the roots than their oxygen as well as their nitrogen may conspire to exalt or hasten the chemical actions on which growth depends.

It is not difficult to suggest experiments by which the former, at least, of these two conjectural opinions may be tested.

A constant production of nitric acid, and probably of ammonia, is going on in the soil. It proceeds most rapidly in soils which abound at once in alkaline and in organic matter. This I have fully explained in my published *Lectures.** I allude to it here only for the purpose of observing that this is probably the reason why the nitrates produce the most striking and profitable effect on land which is *not rich*. On such land they are produced naturally in less abundance.

* Second edition, p. 287.

§ 2.—*Sensible effects produced by the application of the nitrates of potash and soda.*

These nitrates, when applied to growing crops, produce certain sensible effects, which I enumerate separately—

1°. They give a beautiful dark green and luxuriant appearance to the leaf. This they do in common with substances containing ammonia, and hence it is usually ascribed to the influence of the nitrogen which ammonia and nitric acid contain in common. This opinion is supported by the fact that the sulphates and other salts of potash and soda do not produce such a darkening or freshening effect upon the green of the leaf.

2°. They increase the rapidity of growth, the succulence, and the apparent bulk. In the case of grass they do not always add to the weight of the crops when dried into hay, the greater bulk sometimes deceiving the eye and disappointing the hopes of the farmer. It is a question, however, whether this greater succulence, supposing the weight of the crop to be the same, is not in itself a positive money benefit in the feeding of cattle. Such bulky, succulent food ought, when eaten green, to dissolve more completely in the stomach, and thus to yield more nourishment than such as is harder, denser, and of slower growth. It may even be so also with the hay made from the two portions of green grass. The more succulent may swell more in the digestive canal, and, like the green grass, go farther. An inquiry into these opinions offers a wide field of experiment to the practical feeder.

3°. They usually increase the quantity or produce of corn crops, both grain and straw, but impair the quality or market value per bushel. This is said to be especially the case in regard to wheat. The increase in the actual weight of the crops to which they are applied is not, however, invariable.

4°. Like common salt, they render the herbage to which they are applied more agreeable to cattle; so that those parts of a field are eaten especially bare to which the nitrates have been previously applied.

It is truly wonderful to see all these effects produced by such minute additions to the land. One hundredweight of nitrate of soda per acre is only 20 grains to the square foot of land.

These 20 grains contain only 3 grains of nitrogen. Can this minute quantity, supposing it all to enter the plant, really be the sole cause of the observed results?

§ 3.—*Results of past experiments with the nitrates of potash, soda, and lime.*

It is almost unnecessary to insert the results of the numerous experiments which have been made of late years, especially with nitrate of soda. A great number of the published experiments with the latter nitrate have been inserted in my *Lectures.** I shall, therefore, here make a selection, chiefly from results which have not been introduced into any of my previous works.

1°. Experiments upon *wheat.*

a By Mr John M'Clelland, near Wigton, 1843:—

	Grain.	Straw.	Weight of bushel.
Nothing gave	1748 lb.	2824 lb.	63½ lb.
Saltpetre, 1½ cwt.,	1919 ...	3652 ...	63¼ ...
Increase,	171 ...	828 ...	

b By Mr John Haxton, near Cupar-Fife, 1843:—

	Grain.	Straw.	Weight of bushel.
Nothing gave	1549 lb.	3540 lb.	60½ lb.
Saltpetre, 80 lb.,	1968 ...	4472 ...	63¾ ...
Increase per imp. acre,	419 ...	932 ...	3¼ ...

c By Mr John M'Lintock, near Glasgow, 1843:—

	Grain.	Straw.	Weight of bushel.
Nothing,	2689 lb.	3372 lb.	60½ lb.
Saltpetre, 84 lb.,	2664 ...	3136 ...	60½ ...
Diminution per acre,	25 ...	236 ... †	

	Grain.	Straw.
d Nothing,	40 bush.	27 cwt.
Nitrate of soda, 3 cwt.	50 ...	39⅓ ...
Increase,	10 ...	12⅓ ... ‡

* *Lectures on Agricultural Chemistry and Geology,* 2d Edition, p. 593, *et seq.*

† *Transactions of the Highland Society,* January 1849, p. 437.

‡ Ibid. March 1849, p. 531.

These experiments are favourable to the employment of both nitrates as top-dressings, when laid on to the extent of 1½ cwt. per acre, though more favourable to the action of the nitrate of soda. One circumstance in favour of this latter nitrate is its greater solubility, and its tendency to deliquesce in moist air. This enables it to assume or to retain the fluid form in states of the air, which may be too dry to allow the nitrate of potash to diffuse itself through the soil and be taken up by the plant. In the average of cases, therefore, we are entitled to expect a more distinct effect from the nitrate of soda than from saltpetre, unless it be shown by comparative experiments that it is on the special action of the potash or the soda, and not on that of the nitric acid common to both, that their beneficial action in this or that circumstance of soil or crop mainly depends. In the first and third of the above experiments, the application of common salt on a third portion of each of the same fields diminished the crop, in the second it increased the grain by 150 lb., but diminished the produce of straw. It is possible, therefore, that, in this second case, some of the good done by the nitrate of soda was due to the soda it contained and supplied to the soil and to the crop.

2°. Experiments on *barley*. For the sake of comparison, I introduce the results obtained by the application of common salt as well as saltpetre in the following experiments. It is to be regretted that nitrate of soda, applied alone, was not tried at the same time.

a Mr Melvin, near Ratho, Mid-Lothian—

	Grain.	Straw.	Weight per bushel.
No application gave .	41 bush.	25 cwt.	53¼ lb.
Nitrate of potash, 1 cwt.,	44 ...	28 ...	52¾ ...
Common salt, 2 cwt., .	44 ...	24 ...	53 ...

b Mr Fullerton, near Brechin, Forfarshire—

	Grain.	Straw.	Weight per bushel.
Nothing gave . .	44 bush.	28 cwt.	51¼ lb.
Nitrate of potash, 200 lb.	50 ...	31 ...	51¼ ...
Common salt, 200 lb. .	40 ...	25 ...	52¾ ...

c Mr Proudfoot, near Musselburgh, Mid-Lothian—

	Grain.	Straw.	Weight per bushel.
Nothing gave . .	56 bush.	32 cwt.	57 lb.
Nitrate of potash, 140 lb.	56 ...	34⅓ ...	57 ...
Common salt, 3 cwt., .	58 ...	31⅔ ...	57 ...

d Mr Haxton, Cupar, Fifeshire—

	Grain	Straw.	Weight per bushel.
Nothing gave . .	28 bush.	34½ cwt.	51¾ lb.
Nitrate of potash, 80 lb.	31 ...	33 ...	52¾ ...
Common salt, 8 cwt.	34 ...	18 ...	52¾ ...*

Two things are deserving of notice in these experiments. First, the greater weight per bushel of the whole of Mr Proudfoot's barley, and the small effect produced either by saltpetre or by common salt on his field. His crop also was largest, and no doubt his land was in better condition than that of the other experimenters. This is in support of what I stated in the preceding section, that the nitrates are more fitted to benefit the poorer than the richer soils.

Second, that the increase caused by the common salt, in two of the cases, was equal to, or greater than, that caused by the saltpetre. In Mr Haxton's case, the diminution in the straw which accompanied the increase of grain from the application of the common salt is very striking.

It is unfortunate that the want of duplicate experiments prevents us from being certain that the saltpetre really increased any of the crops, except that of Mr Fullerton, who applied it at the rate of about 2 cwt. per acre. The apparent increase in the other cases might have disappeared in duplicate experiments.

The following experiments exhibit the comparative action of the two nitrates on the barley crop, though not in so satisfactory a way as if they had been applied in their equivalent quantities.

a Mr Sim, in 1839, applied the following manures to his field at Drummond, in Ross-shire, on the 3d of May, and sowed his barley on the following day:—

	Grain.	Straw.
Farm-yard manure, 18 double loads, produced	65 bush.	226½ st.
Nitrate of soda, 140 lb. . . .	61½ ...	213 ...
Nitrate of potash, 140 lb. . . .	50 ...	186 ...

This experiment appears to indicate a more favourable action upon barley on the part of the nitrate of soda than the nitrate of potash. To produce an equal effect, however, with 140 lb.

* *Transactions of the Highland Society*, January 1849, p. 434.

of nitrate of soda, 165 lb. of the nitrate of potash ought to have been used. The above result, therefore, even had it been in duplicate, is not so decisive as at first sight it appears to be. The absolute effect of each, it is obvious, could only have been brought out by a comparison of their effects with the produce of other portions of the field to which nothing had been applied.

b In 1843, Mr Finnie, at Swanston, Mid-Lothian, obtained the following results from four experimental plots of barley:—

	Grain.	Straw.
Nothing gave . . .	49 bush.	135 stones
Nitrate of potash, 47 lb. .	50 ...	154 ...
Nitrate of soda, 123 lb. .	60 ...	201 ...
Common salt, 6½ cwt. .	50 ...	151 ...

This experiment would also seem to imply that the nitrate of soda is more useful than the nitrate of potash to the barley crop. But the equivalent weights of the two nitrates are 107 for that of soda, and 127 for that of potash. To produce an equal effect with the 123 lb. of nitrate of soda, therefore, 146 lb. of saltpetre ought to have been applied, whereas the quantity laid on was only 47 lb., which produced no sensible effects. This comparative experiment, like the former, leaves the matter in doubt, and only shows the necessity of new and more carefully conducted trials.

3°. Experiments on *oats*.

a By Mr Main, Mid-Lothian, Scotland, in 1846, on oats after turnips—

	Grain.	Straw.	Weight per bushel.
Nothing gave . .	45 bush.	24 cwt.	40 lb.
Nitrate of soda, 2 cwt. .	45 ...	21 ...	38½ ...

In this experiment the application seems actually to have diminished the produce both of grain and of straw.

b Mr Finnie, Swanston, Mid-Lothian, (Blainslie oats), in 1843—

	Grain.	Straw.	Weight per bushel.
Nothing gave . .	48 bush.	142 stones	42½ lb.
Nitrate of soda, 123 lb.	60¾ ...	225 ...	42¼ ...
Common salt, 6½ cwt.	55½ ...	166 ...	42½ ...

In this experiment the nitrate of soda was very successful in increasing the quantity both of grain and of straw, without

diminishing the weight of the grain per bushel. The common salt in this case was applied in a dose which was large for a top-dressing, and so late as the 13th of May, but rain fell immediately after, and this probably prevented it from injuring the young corn, and made the result a favourable one.

4°. On *tares* by Mr Finnie, Mid-Lothian, in 1843—

Nothing gave . .	846 stones, cut green
Nitrate of soda, 123 lb. .	935 ... ...
Increase, .	89 stones.

The relative quantities of dried produce were not ascertained.

5°. On *grass and clover*, to be cut for hay, numerous experiments have been made and published. I insert only four sets of results in which the effects of different nitrates are compared.

a Mr Gardner, at Barochan, Renfrewshire, in 1844 top-dressed sown grasses on the 7th of May, and obtained from the several portions the following weights of hay per imperial acre—

Nothing yielded . . .	26½ cwt.
Nitrate of soda, 1½ cwt. . .	37 ...
Nitrate of potash, 1 cwt. . .	40½ ...

Both nitrates added largely to the crop; and supposing that duplicate experiments would have made no difference in the above numbers, the nitrate of potash acted more favourably upon the soil than that of soda, since, according to the equivalent numbers, one-fifth more saltpetre ought to have been added to produce an equal chemical effect.

b Two other experiments made at the same place in a subsequent year, on two different fields of loamy soil, gave the following weights of hay per imperial acre:—

	1°.	2°.
Nothing, ...	22½ cwt.	27½ cwt.
Nitrate of soda, 2 cwt. .	51½ ...	56 ...
Nitrate of potash, 2 cwt. .	57 ...	48½ ...

These two results, as they stand, lead to opposite conclusions in regard to the comparative merits of the two nitrates. The addition of one-fifth to the quantity of the nitrate of potash employed might, however, have raised the produce from the

application of this salt in the second experiment, at least to an equality with that obtained by the addition of the 2 cwt. of nitrate of soda; in which case the nitrate of potash would be pronounced the more efficient substance under the circumstances.

c In 1843 Mr Melvin of Ratho, in Mid-Lothian, obtained the following comparative results in the produce of hay:—

Nothing gave . . .	306	stones per acre.	
Nitrate of soda, 2 cwt. . .	449	...	...
Nitrate of potash, 1 cwt. . .	405	...	...

In which the salt of soda appears the more efficient. These discordancies all show the necessity for new experiments.

d By Mr Kuhlmann, near Lille in French Flanders, in 1844. The top-dressings were applied in a state of solution to old grass on the 20th of April, and the produce of the two cuttings of hay was as follows:—

Nothing gave . . .	3820	kilogrammes	per hectare.
Nitrate of soda, 250 kilos. .	5690	...	...
Nitrate of lime (dry,) 250 kilos.	5397	...	...

This is the only experiment with nitrate of lime which I have met with, and the result of its application is very favourable, and encourages repetition. The equivalent weight of the two nitrates of lime and soda are nearly equal, (103 and 107 respectively,) and therefore, when applied in equal quantities, their effects—if not special to them as salts of lime or soda—ought to be nearly alike. In this experiment the nitrate of soda gives the larger return by about 4 per cent, but duplicate experiments might have reversed the position of the two nitrates in this respect.

It must be acknowledged, however, that the subsequent observations of Kuhlmann, in 1845 and 1846, do not support this opinion. In 1845 he applied nothing to any part of this experimental field, but in 1846 renewed his top-dressings—applying to each plot the same weight of the same substance as in 1844. The results of the whole three years were as follows:—

	1844.	1845.	1846.
Nothing gave	3820	4486	3330
Nitrate of soda, . .	5690	4390	5383
Nitrate of lime, . .	5397	4420	4023

The comparative falling-off in 1846 was great enough to invite further inquiry, and rather incites our curiosity than satisfies our convictions.

6°. *On Turnips.* Few experiments with the nitrates have been made upon root-crops, though their known natural occurrence in the sugar-beet and some other roots renders such trials desirable. Several experimenters have reported that, when applied to turnips, the nitrate of soda gave no profit, but the numerical results have not been given.

Mr Barclay of Eastwick Park, Surrey, made some comparative experiments upon turnips in 1839, the size of each plot being 20 roods, and the produce on each as follows:—

Seed drilled with bones and ashes, at the rate of 15 bushels of each per acre, .	gave 30½ cwt.
Seed drilled with nitrate of soda at the rate of 1 cwt. per acre, ...	... 31 ...
Seed and 1 cwt. nitrate, both broadcast,	... 35 ...
Seed drilled, and 1 cwt. nitrate broadcast,	... 38 ... *

On well-manured land, it was stated by Mr Dewdney, whose farm was, I believe, in Surrey, that nitrate of soda did harm to his turnips, though it greatly benefited the succeeding barley crop. The following experiment of Mr Finnie, made at Swanston in Mid-Lothian in 1843, would appear to indicate a similar injury to the turnip crop on land previously well manured with farm-yard dung:—

	Bulbs.		Tops.	
	tons.	cwt.	tons.	cwt.
Farm-yard manure, well made, 16 tons gave	20	8	4	16
Do. and 162 lb. nitrate of soda, ...	19	4	3	6
Do. and 45 lb. bone-dust, ...	17	8	3	6

The weight of the nitrated crop was less, both in bulbs and in tops, than that to which the manure alone was applied. It would therefore appear, at first sight, as if the nitrate had done harm instead of good. I have added the third result, however, which was obtained by the addition of a bushel of bones to the manure, and which was nearly two tons less in the weight of bulbs, to show that this apparent conclusion as to the effect of the nitrate is not a correct one. It is contrary to all experience

* *Journal of the Royal Agricultural Society*, i., p. 428.

that a bushel of bones, added to 16 tons of manure, should have any effect in diminishing the crop. We are, therefore, bound to conclude that the differences in Mr Finnie's results were due to some other cause—to a variation either in the quantity or quality of the manure on the different plots or in the nature of the soil.

I have extracted the above from the tabulated results of thirteen experiments made by Mr Finnie, and published by the Highland Society,* all of which are more or less open to criticism, and exhibit very strikingly the caution with which apparent differences ought to be regarded, and conclusions drawn from numbers set down in a printed table of results.

In a previous chapter, p. 75, I have quoted several examples in illustration of the necessity of duplicate or triplicate experiments, but none of them prove that necessity more than the table of results from which the above have been taken. Were it not for the lessons of care they teach us, we should regret that such experiments had not been withheld from publication.

7°. *On Potatoes*, I find still fewer experiments to have been made with the nitrates. Mr Turnbull, in Dumbartonshire, applied it with the hand around the stems of his potatoes, after they were four to six inches above the ground, at the rate of 1½ cwt. per imperial acre, and obtained an increase of upwards of 3 tons an acre in the crop. This experiment was successful enough to encourage repetition.

§ 4.—*Results of experiments with nitrate of soda, applied in different proportions to the same crop.*

As this is a point which is deserving of experimental investigation, I shall insert, in a separate section, the only two experiments I have met with which exhibit the effects of different quantities of the same nitrate applied under the same circumstances to the same crop.

1°. In 1844, Mr Gardiner, at Barochan in Renfrewshire, applied to two portions of the same field of sown grasses, 1½ and 2 cwt. of nitrate of soda respectively, with the following results per imperial acre :—

* *Transactions*, October 1844.

			Increase.
No application	yielded $26\frac{1}{2}$ cwt. of hay.		
Nitrate of soda, $1\frac{1}{2}$ cwt.	... 37	...	$10\frac{1}{2}$ cwt.
Nitrate of soda, 2 cwt.	... 54	...	$27\frac{1}{2}$ ...

If the field was uniform in quality and natural productiveness, these results indicate a much larger proportional increase from the additional half cwt. in the second experiment, than from the $1\frac{1}{2}$ cwt. in the first. Is such a result likely often to follow from such additional doses of fertilising substances?

2°. Mr Kuhlmann, in 1843, applied to old grass-land in the neighbourhood of Lille, in French Flanders, nitrate of soda in the proportions of 133 and 266 kilogrammes per hectare respectively, with the following results per hectare:—

			Increase.
No application	gave 4000 kilos. of hay.		
Nitrate of soda, 133 kilos.,	... 4800	...	800 kilos.
Nitrate of soda, 266 ...	... 5725	...	1725 ...

In this case the increase of produce was nearly in proportion to the quantity of nitrate applied—133 kilogrammes causing an increase of 800, and 266 kilogrammes an increase of 1725 kilogrammes of dry hay.

These experiments give rise to various questions, such as—to what extent can the increase in the doses of a manuring substance be profitably carried?—on what crops will the larger doses be most economically applied?—on what soils will they be most successful? To solve these questions, further experiments are to be desired.

§ 5.—*Suggestions for new experiments with the nitrates of potash, soda, lime, and magnesia.*

I offer the following suggestions for further experiments with these nitrates:—

1°. The effect of each or any of these nitrates, applied alone as a top-dressing to corn-crops, or as an application to root-crops after they are above the ground. Especially, their effects upon wheat and barley, and upon beets, turnips, and cabbage, ought to be accurately noted.

2°. Experiments with equivalent quantities of the three nitrates tried against one another in the same circumstances and upon the same crop. Does the nitrate of soda really promote the growth of barley more than the nitrates of potash or lime do?

3°. With each of the nitrates tried in different doses applied all at once—for example, in doses of ½, 1, 1½, 2, 2½, and 3 cwt. per acre. These will throw light upon the interesting question suggested by the experiments detailed in the preceding section.

4°. With the same quantity applied at different periods—in March, April, May, &c.,—and with the same quantity divided into two or three portions, and applied at as many successive periods.

5°. Do they really, and in all cases, affect—that is, injure—the quality of corn, especially of wheat?—and what is the nature of the difference they are said to cause? This may require a chemical, as well as a practical and mechanical examination of the grain.

6°. The effects of these nitrates on soils of different degrees of richness. Do they pay best when applied to such as are poor in available (not inert) vegetable matter?

7°. Their effects compared with equivalent quantities of the carbonates of potash and soda, or of the chlorides of potassium, sodium, and calcium. By these substances the alkaline matter, without the nitric acid, of the nitrates, would be brought within the reach of the plant, and the true value of the nitric acid would be illustrated.

8°. Their effects, compared with those of other substances containing much nitrogen, such as urea, gelatine, salts of ammonia, &c., and which have nearly as great a degree of solubility. To this class of experiments I shall revert in a succeeding chapter.*

9°. As I have already thrown out the conjecture that some of the special effects of the nitrates in the soil or in the plant may be due to the large proportion of oxygen they contain, and the ease with which they give up this oxygen, comparative trials with other substances containing much oxygen would not be void of interest. Among such substances, the chlorate of potash is one of the best. This salt is expensive, and we could scarcely hope ever to use it for agricultural purposes; but with

* See Chapter xiii.

the view of throwing light on this theoretical question, small experiments might be made with it upon different plants without incurring any serious expense. It is not unlikely that, by such experiments, light may be thrown on the differences observed in the comparative actions of the nitrates and the salts of ammonia in similar circumstances.

10°. Their special and precise effects on the blossoming of flowers is an interesting subject of inquiry. When flower-buds are plucked and waxed up so as to prevent their opening, they may, a week after, be made to blossom by removing the wax, and placing the stems in a solution of nitre. Is there any specially useful action exercised by the nitrates over plants at the season of blossoming? Is there any connexion between such action and the nitrogen which flower-leaves are said to give off in the daytime?

11°. Will the more succulent nitrated grass—even though it may yield no greater a weight of hay—go farther in feeding cattle than the less bulky unnitrated grass from the same field?

12°. And this leads to certain purely chemical, though most important, practical inquiries, which I only mention here. Is nitrated hay, weight for weight, more nutritive than such as grows naturally, or without any such top-dressing? Does it contain more nitrogen? Do the seeds of plants—wheat, barley, &c.—contain a larger percentage of nitrogen when they have been dressed with any of these nitrates? Are turnips, or beets, or cabbage more nutritive? These questions are very important. I shall revert to them again, when, in a subsequent chapter, I come to enumerate the various theoretical and practical questions, for the solution of which conjoined researches in the field and in the laboratory are, in the present state of our knowledge, especially required.*

13°. I specially indicate experiments with nitrate of magnesia as desirable, especially upon corn-crops, in the seeds of which magnesia is known to abound. No trials have ever been made with this substance; and yet with it, as well as with the nitrate of lime, interesting results may be obtained. The equivalent quantity of dry nitrate of magnesia is 93½.

* See also Chapter xiii. § 2 and 3.

CHAPTER XII.

Experiments with the salts of ammonia. Composition of caustic ammonia, and of the carbonate, sulphate, muriate, phosphate, nitrate, acetate, oxalate, and humate of ammonia. Functions performed by the salts of ammonia in the soil and in the plant. Results of experiments with carbonate of ammonia and with ammoniacal liquor. Results of experiments with sulphate of ammonia. Results of experiments with muriate of ammonia (sal-ammoniac.) Results of comparative experiments with the different salts of ammonia, and with the nitrates of potash and soda.

Ammonia and its salts are now recognised to be very generally useful in promoting vegetable growth. They impart to plants a beautiful green colour; increase the rapidity, and prolong the duration of their growth; make them more succulent and grateful to cattle; and, for the most part, add to the bulk and weight of the crop. In regard to them, three points require to be investigated by experiment,—*first*, their special effect upon particular crops in different soils and circumstances; *second*, their comparative effects; and *third*, their comparative economy to the practical farmer.

§ 1.—*Composition of caustic ammonia, and of the carbonate, sulphate, muriate, phosphate, nitrate, acetate, oxalate, and humate of ammonia.*

Ammonia or caustic ammonia is a kind of air or gas which is readily prepared by mixing together quicklime and sal-ammoniac, each in the state of fine powder. It is colourless, but has the strong pungent odour familiarly known in hartshorn and smelling-salts. Its presence is readily detected, not only by its smell, but by the white fumes it produces when a feather, dipped in muriatic acid or in strong vinegar, is brought near to the place where its presence is suspected. It consists of—

Nitrogen, ...	82·35
Hydrogen, ...	17·65
	100

Water absorbs from 400 to nearly 700 times its bulk of this gas, acquiring, at the same time, all the sensible properties of the gas. The common hartshorn of the shops is such a solution of ammonia in water.

The salts of ammonia which have been, or are likely to be, employed—either with advantage in practical agriculture, or with the prospect of interesting theoretical results—are the carbonate, the sulphate, the muriate, the nitrate, the phosphate, the acetate, the oxalate, and the humate.

These salts are composed as follows,—

1°. Carbonate of ammonia of the shops . .	consists of	Carbonic acid,	28.8
		Ammonia,	55.9
		Water, .	15.3
			100

This salt gives off ammonia when exposed to the air; hence the powerful odour to which it owes the name of smelling-salts. In consequence of this property, it seldom contains so much ammonia as the above numbers represent. When it ceases to give off this strong smell, it contains only 21½ per cent of ammonia. It is then what chemists call *bi*-carbonate, the pure smelling-salts being *sesqui*-carbonate of ammonia. When dissolved in water, on the other hand, as it is in ammoniacal liquor, it loses carbonic acid, and becomes what is called the neutral carbonate, which contains 39 per cent of ammonia.

This salt of ammonia, therefore, is of inconstant composition, and, consequently, is not well adapted for accurate field experiments.

2°. Sulphate of ammonia in dry crystals .	consists of	Sulphuric acid,	60.6
		Ammonia,	25.8
		Water, .	13.6
			100

This salt is without smell, and, when pure, is constant in composition.

3°. Muriate of ammonia, or sal-ammoniac, .	consists of	Muriatic acid,	68.2
		Ammonia,	31.8
			100

This salt is also without smell, and is of constant composition. It deliquesces slowly when exposed to moist air.

4°. Phosphate of ammonia consists of	Phosphoric acid,	53.9
	Ammonia,	25.7
	Water, .	20.4
		100

This salt effloresces slightly in the air, and loses a part of its ammonia. It is much more stable, however, than the carbonate. It exists in the urine of man, and in that of carnivorous animals. It is prepared in the same way as the phosphate of soda, by treating an excess of burned bones with sulphuric acid, decanting the liquid, saturating it completely with carbonate of ammonia, and setting it aside to crystallise.

5°. Nitrate of ammonia consists of	Nitric acid, .	67.5
	Ammonia, .	21.2
	Water, .	11.3
		100

This salt deliquesces readily in moist air, and slowly loses a small portion of its ammonia.

6°. Acetate of ammonia is prepared by saturating common vinegar with carbonate of ammonia, and evaporating by a gentle heat. It may be more cheaply made by mixing crude wood vinegar (pyroligneous acid) with the ammoniacal liquor of the gas-works. The composition of this salt has not been accurately determined. I notice it here chiefly in consequence of the statement of Persoz, (see page 95,) that a very small quantity of it applied to certain plants produces a decidedly injurious effect,—a statement which is deserving of careful experimental examination.

7°. Oxalate of ammonia consists of	Oxalic acid,	58.1
	Ammonia, .	27.4
	Water, .	14.5
		100

This salt crystallises in beautiful small prisms, and is soluble in 28 parts of cold water. It is much used in the laboratory,

and, from its price, can never be employed in practical agriculture. It will be interesting, however, to ascertain the nature of its influence upon growing plants.

8°. Humate of ammonia is formed by digesting caustic ammonia or carbonate of ammonia on rich vegetable mould, or on dried and powdered peat. The ammonia causes the decaying vegetable matter to swell very much, and forms a dark brown solution of humate of ammonia. The composition of this humate is not accurately known. It is deserving of being made the subject of field experiment, however, because of the great probability which exists that one of the functions of ammonia in the soil is to form such soluble combinations with the organic matter contained in the soil, and thus to make it capable of entering into the roots of plants.

All the salts of ammonia are readily soluble in water, and they all give off ammonia when mixed with quicklime or slaked lime, or with caustic potash, soda, or magnesia; more slowly when mixed with the carbonate of potash, (pearl ash or wood ashes,) or with the carbonate of soda, (common soda of the shops, or soda ash,) and still more slowly when mixed with carbonate of lime, (mild lime or chalk,) or with carbonate of magnesia.

§ 2.—*Functions performed by the salts of ammonia in the soil and in the plant.*

1°. *Functions in the soil.*—The chemical functions performed by ammonia in the soil will vary with the state of chemical combination in which it is used.

a Caustic ammonia and carbonate of ammonia will neutralise acid substances, if any such exist in the soil—will decompose earthy and metallic sulphates and chlorides, forming sulphate of ammonia and sal-ammoniac—will combine with and render soluble the humic, ulmic, and other organic acids, which will thus be rendered available to the nourishment of plants, and, in the presence of lime or alkaline carbonates, will be slowly converted into nitric acid.

b Sal-ammoniac, in the presence of the carbonates of lime or magnesia, will be partially or completely decomposed, forming chloride of calcium or magnesium, and carbonate of ammonia.

The latter salt will then act in one or other of the ways above described.

c Sulphate and phosphate of ammonia will, in like manner, yield their acid more or less completely to potash, to soda, to lime, and perhaps to magnesia, forming sulphates and phosphates of these substances, while their ammonia is converted into carbonate.

d Nitrate of ammonia will give up a part of its acid to any earthy or alkaline carbonates which may exist in the soil, and will be thus partly converted into carbonate. Its acid may also contribute, by the oxygen it contains, to promote the decomposition of organic matter; but this will only take place beneath the surface, where the light does not penetrate, and where much organic matter is present.

Nitrate of ammonia exists in and is naturally formed in most soils. It yields its nitric acid to the carbonates of lime and magnesia when they are present in the soil, and is itself converted into carbonate. Thus, while it brings the lime and magnesia into a state in which they can readily enter the plant, the ammonia becomes itself capable of decomposing sulphates and chlorides, either in the soil or in the plant.

e The acetate, oxalate, and humate of ammonia, may all undergo slow oxidation in the surface soil, producing nitric acid from the ammonia, and carbonic acid from the acetic, oxalic, and humic acids which they contain.

2°. *Functions in the plant.*—The salts of ammonia may undergo the above changes more or less completely in the soil, but they may also enter directly into the roots of plants, and perform certain functions which are important to their healthy and rapid growth. Thus,—

a They supply nitrogen—an element very necessary to the growing plant—in a form in which it is immediately available for the production of those nitrogenous compounds which not only form an important part of the substance of the plant, but appear also to preside over those chemical changes constantly taking place in its sap, and upon which the health and rapidity of its growth depend.

These substances—protein compounds they are called—exist in large proportion in the extremities of the roots, and are

supposed to be formed there, and to be afterwards carried up to the other parts of the plant by the ascending sap. Ammonia, and especially when it enters in combination with humic acid, is peculiarly adapted to the production of these compounds,* and hence, probably, one reason why its action upon growing plants is in many cases so immediate and striking.

b Among the intelligible chemical uses of ammonia in the sap, I may mention that, when it enters the roots in the state of carbonate, it has the power, and probably exercises it, of decomposing the alkaline sulphates and chlorides, converting them into carbonates, and thus preparing them to combine with the organic acids formed in the sap, with which we find them so generally united.

c The salts of ammonia carry into the plant the sulphuric, muriatic, humic, and other acids with which they may happen to be combined, and thus supply other elements which are directly or indirectly necessary to the production of the parts of the plant.

d They are all the producers of, or are necessary to the production of numerous chemical changes in the sap. These changes are as yet by no means understood, but we know that they take place, and that nitrogen, sulphur, phosphorus, &c., are necessary to the production of them. None of the substances we have it in our power to apply to growing plants is capable of undergoing more varied transmutations than ammonia. Such transmutations it not only itself undergoes in the interior of plants, but, in so changing, it causes, or is accompanied by, similar chemical changes in other substances also—without which constant and varied metamorphoses, the healthy growth of plants could not proceed.

§ 3.—*Experiments with carbonate of ammonia, and with ammoniacal liquor.*

I am not aware of any field experiments which have been made with carbonate of ammonia in any other form than that in which it occurs in the ammoniacal liquor of the gas-works. This liquor varies in strength, and, besides carbonate, it contains

* See my *Lectures on Agricultural Chemistry and Geology*, 2d edition, p. 243.

also sulphate of ammonia and sal-ammoniac in uncertain proportions. Although, therefore, when diluted with three or four times its bulk of water, this liquid has proved a very valuable application to grass land,* to young corn, and to many other crops, the results obtained with it do not satisfactorily bring out the unaided effects of carbonate of ammonia. I give examples of its effect upon wheat, upon oats, and upon grass cut for hay.

1°. *On wheat.*—Mr Bourhill, at Musselburgh in Mid-Lothian, applied it to a crop of wheat, with the following increase per imperial acre:—

	Grain.	Straw.
Nothing gave . . .	23 bush.	57 cwt.
Ammoniacal liquor, 240 gallons,	35 ...	87½ ...

The increase here was very considerable, both in grain and in straw.

2°. *On oats.*—In 1842, Mr M'Lintock, near Glasgow, top-dressed separate portions of a field of Blainslie oats with various substances, and, among others, with 400 gallons an acre of carbonate of ammonia, by which I understand him to mean ammoniacal liquor, with the following results per imperial acre:—

	Grain.	Straw.	Chaff.
No application gave . .	35¾ bush.	92 stones	304 lb.
Carbonate of ammonia, 400 gallons,	45½ ...	120 ...	320 ...
Rape-cake, 280 lb., . .	43½ ...	108 ...	320 ...

In this case the application was evidently very useful, more so than 2½ cwt. of rape-cake. It may, I believe, in many cases, be pretty safely concluded, that where rape-cake does good, the impure carbonate of ammonia of the gas-works may be applied with advantage also. It is less useful when the land is already rich than where it is comparatively poor in animal and vegetable matter.

3°. *On grass.*—Applied at the rate of 150 gallons per acre, diluted with 500 gallons of water, it gave, per acre,—

Undressed, ...	20½ cwt. of hay
Dressed, ...	61½ ... ...
Increase,	41 ... ...

* See my *Lectures*, 2d edition, p. 617.

Here the crop was nearly tripled; an effect dependent, no doubt, in some measure on the state of the land.

These experiments prove the value of ammoniacal liquor, and afford a strong presumption in favour of carbonate of ammonia applied alone; but, as I have already said, they do not satisfactorily bring out the special and unaided action of carbonate of ammonia.

Pure carbonate of ammonia is too high in price to be recommended for field experiments, but trials on a small scale may be made with it, especially in comparison with the other salts of ammonia, which are more usually employed as manures.

§ 4.—*Results of experiments with sulphate of ammonia.*

The sulphate has been more extensively employed as a manure, and more generally with a profit, than any other of the salts of ammonia. This has arisen chiefly from its greater abundance, and from the comparative lowness of its price. It is to corn and grass crops that it has hitherto been most frequently applied.

1°. *On wheat.*—In 1847, Mr Main applied it on the 1st of February to a portion of Taunton-Dean wheat, with the following result in comparison with sulphate of soda:—

	Grain.	Straw.
No application gave . .	27½ bush.	19⅓ cwt.
Sulphate of ammonia, 2 cwt.	33¼ ...	29⅓ ...
Sulphate of soda, 2 cwt. .	32 ...	24⅔ ..

I have added the result of the action of sulphate of soda, for the purpose of marking the difference in the effects of the two sulphates. Both largely increased the produce of grain, and nearly to the same extent, but the sulphate of ammonia added about five hundredweight more to the produce of straw. It had the usual effect of the salts of ammonia in promoting growth more than mineral sulphates are observed to do.

2°. *On oats.*—The following table exhibits the results of four experiments made upon oats, top-dressed in the spring of 1843, on different farms near Turriff, in Aberdeenshire:—

a At Darra, after turnips—

	Grain.	Straw.	Chaff.
Nothing gave . .	57 bush.	31 cwt.	302 lb.
Sulphate of ammonia, 2 cwt.	59 ...	42 ...	118 ...

b After lea, at Rothie Brisbane—

	Grain.	Straw.	Chaff.
Nothing gave . .	54½ bush.	40 cwt.	640 lb.
Sulphate of ammonia, 2 cwt.	86 ...	59 ...	136 ...

c After lea, at Mill of Laithers—

	Grain.	Straw.	Chaff.
Nothing gave . .	43 bush.	20 cwt.	272 lb.
Sulphate of ammonia, 2 cwt.	56 ...	28 ...	412 ...

d After lea, at Lower Cotburn—

	Grain.	Straw.	Chaff.
Nothing gave . .	35½ bush.	20 cwt.	300 lb.
Sulphate of ammonia, 2 cwt.	57½ ...	34 ...	336 ...

In all these experiments, except the first after turnips, the increase both of straw and grain was very considerable. The manure employed for the turnip crop of the previous year may account for the smaller increase in grain in the first experiment made at Darra.

It will interest the physiologist to observe how very different the weights of chaff are with which the grain in the several crops was covered.

3°. *On turnips* few experiments have been made and recorded. Mr Fleming, in 1842, made one upon yellow turnips, to which no farm-yard manure was added. The land was trenched out of grass, and must have been in good heart, or it would not have yielded from 11 to 13 tons of bulbs without any manure.

Nothing, 1st plot, gave	11 tons	8 cwt.	of bulbs.
... 2d	12 ...	17 ...	..
Sulphate of ammonia, 1 cwt. . .	24 ...	11 ...	...
Sulphate of magnesia, 1 cwt. . .	14 ...	17 ...	...
Nitrate of soda, 1 cwt. . .	27 ...	2 ...	...
Rape-dust, 15 cwt.	24 ...	11 ...	... *

* See my *Lectures on Agricultural Chemistry*, 1st edition, Appendix, p. 56.

This experiment, supposing, as the large differences seem to justify us in doing, that the results are to be depended upon in the absence of duplicate experiments, is very interesting. In trenched land it seems to say that substances containing nitrogen are likely to be deficient, and the use of them, therefore, on such land profitable to the farmer. It is not unimportant to remark, however, that the increase of hay was by no means in proportion to the absolute quantity of nitrogen in the several manures that contained it. Thus the proportions of nitrogen added, and the increase of bulbs in the three cases were as follows:—

	Nitrogen added per acre.	Increased produce per acre.
Sulphate of ammonia, 1 cwt. .	23.7 lb.	11 tons 14 cwt.
Nitrate of soda, 1 cwt. . .	18.6 ...	14 ... 5 ...
Rape-cake, 15 cwt. . .	72.5 ...	11 .. 14 ...

This table shows that the smallest addition of nitrogen produced the largest increase, while the largest addition (in the rape-cake) gave the smallest increase of crop. We shall consider this kind of anomaly more at length in the succeeding chapter.

4°. *On grass cut for hay*, numerous experiments have been made. I shall only insert a few of the results which have been made public.

a In 1843 Mr Melvin, at Ratho, Mid-Lothian, top-dressed his grass with sulphate of ammonia, and with the nitrates of potash and soda, with the following results:—

Nothing gave, per acre, ...	306	stones of hay.
Sulphate of ammonia, 1 cwt. . .	396	...
Nitrate of soda, 2 cwt. . . .	449	...
Nitrate of potash, 1 cwt. . .	405	...

The increase was large with all these applications. I shall in a subsequent section consider how far it was in proportion to the quantity of nitrogen the several applications contained.

b The three following experiments were made at Barochan in 1845 upon three different fields, the first being sown grasses, the two others old lea, top-dressed each with 2 cwt. of sulphate of ammonia per acre. I introduce also the results of the appli-

cation of muriate of ammonia to other portions of the same fields:—

	Sown grasses.	Six years old lea.	Thirty years old lea.
Nothing gave . . .	$41\frac{1}{2}$ cwt.	$22\frac{1}{2}$ cwt.	$27\frac{1}{2}$ cwt.
Sulphate of ammonia, 2 cwt.	$76\frac{1}{3}$ ...	40 ...	40 ...
Muriate of ammonia, 2 cwt.	72 ...	$48\frac{1}{4}$ ...	38 ...

In all these cases also the increase was large, and especially so in the sown grasses. On the whole, the equal weights of sulphate and muriate of ammonia may be said to have produced nearly equal effects; though, on looking back to page 100, it will be seen that the equivalent weights of these two salts are such that 67 lb. of muriate ought to produce as great an effect as 94 lb. of sulphate, supposing the acids they respectively contain to exercise no special or peculiar action on the growth of grass.

c I quote only one other experiment made at the Mill of Laithers, in Aberdeenshire:—

Nothing gave	140 stones of hay.
Sulphate of ammonia, 2 cwt. . .	$173\frac{1}{2}$ ...
Nitrate of soda, $1\frac{1}{2}$ cwt. . . .	163 ...

It will appear from all the results I have inserted in this section, and which are not selected to prove any view of my own, but are introduced simply as they have come to my hands, that the sulphate of ammonia, skilfully and prudently used, may, in the hands of the intelligent and enlightened farmer, prove a means of considerably augmenting his ordinary profits.

§ 5.—*Results of experiments with muriate of ammonia, (sal ammoniac.)*

In the preceding section I have given the results of certain comparative experiments with the sulphate and muriate of ammonia. I refer the reader to these results of the application of the muriate, and introduce here a few others only.

1°. *To wheat.* Mr Fleming, of Barochan, obtained from a small application only a small increase of grain. Thus—

No dressing gave . . .	25 bushels, each 61 lb.
Sal-ammoniac, 20 lb. . .	$26\frac{1}{4}$ ... ... 62 ...

The quantity applied in this case was too small to yield any decisive result.

2°. *On oats.* *a* In 1846 Mr Main, at Whitehill, Mid-Lothian, applied it to oats after turnips, top-dressed on the 26th of May:—

	Grain.	Straw.
Nothing gave	45 bushels	24 cwt.
Muriate of ammonia, 2 cwt. . .	71½ ...	32 ...

The larger dose applied in this experiment gave a striking increase both in grain and straw.

b In 1842 Mr M'Lintock, near Glasgow, applied it on the 4th of April to Blainslie oats, succeeding a crop of oats in the previous year. The following table shows the results in the immediate corn crop, and the after hay crop of 1843:—

	Grain.	Straw.	Chaff.	Hay in 1843.
Nothing gave . .	35¾ bush.	92 stones	304 lb.	201 stones
Muriate of ammonia, 1 cwt.	45⅓ ...	120 ...	260 ...	195 ...

3° *On rye.* Mr Fleming in one of his early experiments obtained from a crop of rye, slightly dressed with sal-ammoniac, the following result:—

	Grain.	Straw.
Nothing gave	14 bushels	36½ cwt.
Sal-ammoniac, 20 lb. . . .	19 ...	43½ ...

This small top-dressing produced apparently a considerable effect, but the whole crop was too small to allow any confidence to be placed on single results.

4°. *On grass*, cut for hay.

a At Barochan, in 1846, it was applied to three different fields of grass, afterwards cut for hay. The top-dressing was made on the 28th and 30th of April; horn-dust was applied at the same time in comparative experiments:—

	1°. Sown grasses.	2°. Six years old lea.	3°. Thirty years old lea.
No application gave .	41½ cwt.	22½ cwt.	27½ cwt.
Muriate of ammonia, 2 cwt.	72 ...	48¼ ...	38 ...
Horn-dust, 1½ cwt. .	—	48 ...	31¾ ... *

The increase in the sown grasses, by the application of the

* *Transactions of the Highland Society*, July 1847.

muriate of ammonia, was especially remarkable. In the second experiment the horn-dust had nearly an equal effect with the sal-ammoniac.

b Mr Kuhlmann applied it in the two successive years of 1845 and 1846, the former, in French Flanders, a very wet, the latter a very dry year, with the following effects upon the produce of hay in each year, per hectare:—

	1845.		1846.
	First cut.	Second cut.	
No application gave .	5608	2136	3519
Sal-ammoniac, 200 kilos. .	7665	1723	5576
Difference,	2057	413	2057

In both years this application gave an increase of hay, but most in the dry year 1846. The force of the sal-ammoniac, in 1845, was expended on the first cutting, unless we suppose that the great fall of rain may have washed some of it out of the soil.

On the whole, were it a cheaper material, the application of muriate of ammonia might be safely recommended as worthy of trial, even on the part of the farmer who seeks for profit only.

§ 6.—*Results of experiments with nitrate of ammonia.*

The only experiment made by weight and measure with nitrate of ammonia, with which I am acquainted, has been published by Mr M'Lintock, of Harley Works, near Glasgow. He applied it in 1842 to a second year's crop of Blainslie oats, top-dressed on the 13th of May, with the following results:—

	Grain.	Straw.	Chaff.	Hay in 1843.
No application, . gave	35¾ bush.	92 stones	304 lb.	201 stones
Nitrate of ammonia, 96 lb. ...	57 ...	161 ...	448 ...	197½ ...

There was here a very considerable increase both in grain and in straw. Even the chaff was nearly doubled in weight. The next year's hay, however, was not sensibly affected.

The fact that both the ammonia and the acid with which it is combined in this salt contain nitrogen in a form in which

plants are accustomed to take up and appropriate it, has rendered it probable that, weight for weight, the nitrate of ammonia would more largely promote the growth of plants than any other salt of ammonia. It is expensive, however, and is not a usual article of commerce, and therefore few experiments have hitherto been made with it. But it is very desirable that such experiments should be made, as they would not only throw light on some interesting points of theory, but might lead to useful suggestions in matters of practice.

§ 7.—*Results of comparative experiments with the different salts of ammonia, and with the nitrates of potash and soda.*

It will be interesting to compare together, so far as our present defective materials will allow, the actions of the several salts of ammonia upon the same crop, and the effects produced at the same time by the nitrates of potash and soda. The only comparative experiments of this kind I have been able to meet with are the following upon oats and hay:—

1°. *On oats*, after turnips, in 1846, Mr Main applied the sulphate and muriate of ammonia in comparison with nitrate of soda and the sulphates of soda and magnesia. The soil was light and sandy, and had been long cultivated without rest.

	Grain.	Straw.	Increase of grain.
No application . . gave	45 bush.	24 cwt.	
Sal-ammoniac, 2 cwt.	71½ ...	32 ...	26½ bush.
Sulphate of ammonia, 2 cwt. ...	62 ...	27⅓ ...	17 ...
Sulphate of soda, 2 cwt. ...	64½ ...	26¼ ...	19½ ...
Sulphate of magnesia, 2 cwt. ...	58¾ ...	26½ ...	13¾ ...
Nitrate of soda, 2 cwt.	45 ...	21* ...	— ...

In this experiment all the applications, except the nitrate of soda, did good. The action of the sal-ammoniac was most striking, but that of the sulphate of soda exceeded that of the sulphate of ammonia. If these results could be confidently relied on, we might suspect from them—

a That sal-ammoniac exercised a special action, under the circumstances, which neither the sulphate of ammonia nor the nitrate of soda was capable of doing.

b That the sulphuric acid in the three sulphates had more

* *Transactions of the Highland Society*, January 1848, p. 177.

to do with their nearly equal action than the ammonia, soda, or magnesia with which it was combined.

c That the nitrogen in the nitrate of soda was not in a condition to contribute to the growth of the crop.

But we should be wrong to draw conclusions in regard to any of these points. Suspicions of this kind are only useful when they lead to renewed and more careful experiments.

2°. Again to oats, the second year's crop of this grain on the same field, Mr M'Lintock, near Glasgow, in 1842, applied the following top-dressings on the 13th of May:—

	Grain.	Straw.	Chaff.	Hay crop in 1843.
No application gave .	35¾ bush.	92 stones	304 lb.	201 stones
Sulphate of ammonia, 1 cwt.	45⅓ ...	120 ...	260 ...	195 ...
Muriate of ammonia, 104 lb.	50 ...	140 ...	320 ...	204½ ...
Nitrate of ammonia, 96 ...	57 ...	161 ...	448 ...	197½ ...
Nitrate of potash, 90 ...	60½ ...	176 ...	320 ...	171 ...
Nitrate of soda, 90 ...	44 ...	128 ...	352 ...	224* ...

These results suggest conclusions somewhat different from those of Mr Main. Here the nitrate of potash gave the largest crop, though it was applied in smaller quantity than the salammoniac. The nitrate of ammonia came next, and the sulphate of ammonia produced about an equal effect with the nitrate of soda, in the quantities in which they were in this case applied. There is nothing in these results to lead us to suppose that nitrogen, in the form of nitric acid, is not equally efficacious with nitrogen in the form of ammonia. For while the nitrate of potash beat all the salts of ammonia, that of soda was as efficacious as the sulphate of ammonia, and, alone of all the applications, caused an increase in the after-crop of hay.

3°. *On grass cut for hay*, at Barochan, on three separate fields in 1844, the following comparative results were obtained:—†

	Sown grasses.	Lea six years old.	Lea thirty years old.
No application gave .	41½ cwt.	22½ cwt.	27½ cwt.
Muriate of ammonia, 2 cwt.	72 ...	48¼ ...	38 ...
Sulphate of ammonia, 2 cwt.	76⅓ ...	40 ...	40 ...
Nitrate of potash, 2 cwt.	89 ...	57 ...	48½ ...
Nitrate of soda, 2 cwt. .	81½ ...	51½ ...	56 ...

* *Transactions of the Highland Society*, January 1849, p. 449.

† *Transactions of the Highland Society*, July 1847, p. 21 *et seq.*

On these grass fields the nitrates were more successful than the salts of ammonia, and in only one of the cases did the muriate exhibit a more favourable influence than the sulphate of ammonia.

4°. Again on grass, M. Kuhlmann made two comparative series of experiments, the first with sulphate of ammonia, and the nitrates of soda and lime; the second with muriate of ammonia and the nitrate of soda. These results were as follows, per hectare:—

a The same plots were top-dressed with equal quantities of the salts in 1844 and 1846, being left without top-dressing in 1845.

		1844.	1845.	1846.	Total increase.
No application gave . .		3820 kilos.	4486 kilos.	3330 kilos.	
Sulphate of ammonia,	250 kilos.	5564 ...	4170 ...	5193 ...	3291 kilos.
Nitrate of soda,	250 ...	5690 ...	4390 ...	5383 ...	3827 ...
Nitrate of lime,	250 ...	5397 ...	4420 ...	4023 ...	2204 ...

b In his second experiment, equal applications of muriate of ammonia and nitrate of soda were made in 1845 and 1846, to the same plots of the same old grass field, with the following results, per hectare:—

		1845.	1846.	Total increase.
No application gave . .		7744 kilos.	3519 kilos.	
Muriate of ammonia,	200 kilos.	9388 ...	5576 ...	3700 kilos.
Nitrate of soda,	200 ...	9543 ...	4523 ...	2803 ...

In the former experiment the increase upon the two years was greater from the application of the nitrate of soda, than from that of the sulphate of ammonia. In the second, though the nitrate produced a large increase, it was surpassed by that which was caused by the addition of the muriate of ammonia.

The experiments brought together in this section present the only data we as yet possess from which we can hope to extract an answer to the question, Whether or not the sensible effect of the salts of ammonia and of the nitrates is in direct proportion to the quantity of nitrogen they respectively contain? I shall examine them in reference to this point in the following section.

CHAPTER XIII.

Experiments with the salts of ammonia—*continued*. Proportions of nitrogen contained in the nitrates and in the salts of ammonia. Comparison of these proportions with the effects they have been found to produce upon the quantity of the crop. The state of chemical combination in which the nitrogen exists in a manure affects its influence. Comparative experiments with gelatine, with rape-cake, and with the sulphate of ammonia, on the quantity of the crop. Influence of the quantity of nitrogen, and of the state of chemical combination in which it exists in a fertilising substance, on the quality of a crop to which it has been applied. Suggestions for experiments with the carbonate, nitrate, muriate, and sulphate of ammonia. Suggestions for experiments with the acetate and oxalate of ammonia. Suggestions for experiments with the phosphate of ammonia, the ammoniacal phosphate of soda, and the ammoniacal phosphate of magnesia. Suggestions for comparative experiments with gelatine, oil-cakes, urea, uric acid, and nitrate of urea.

§ 1.—*Are the effects of the salts of ammonia and of the nitrates on the quantity of the crop in direct proportion to the quantity of nitrogen they respectively contain?*

THE relative proportions of nitrogen contained in the nitrates of potash, soda, and lime, and in the salts of ammonia employed in the comparative experiments, of which the details were given in the preceding section, are represented by the following numbers:—

	Nitrogen per cent.
Sulphate of ammonia contains	21.2
Muriate of ammonia, (sal-ammoniac,) . . .	26.2
Nitrate of ammonia, ...	35.1*
Nitrate of potash, ...	13.97
Nitrate of soda, ...	16.58
Nitrate of lime, ...	17.14

With the aid of these numbers we shall examine the above experiments. They will enable us to test the influence of the

* Of this nitrogen one-half is in the state of nitric acid, and one-half in that of ammonia.

nitrogen contained in the several salts employed in them. Having already shown the absolute increase of crop obtained by the use of each, I shall here calculate and exhibit in a tabular form only the increase obtained by the use of each application, supposing the quantity of nitrogen added by it to have been one hundred pounds.

1°. In Mr Main's experiment upon oats, a hundred pounds of nitrogen, in the form of

	Increase for every 100 lb. of nitrogen applied. Grain.	Straw.
Sulphate of ammonia, gave .	$37\frac{3}{4}$ bush.	$7\frac{1}{3}$ cwt.
Sal-ammoniac, . . .	$47\frac{3}{4}$ ...	$14\frac{1}{3}$ ...
Nitrate of soda, . . .	no increase	none

This experiment lends no support whatever to the opinion that the sensible increase of crop caused by these applications on the same soil has a direct relation to the percentage of nitrogen they respectively contain.

2°. In Mr M'Lintock's experiment upon oats, a hundred pounds of nitrogen, in the form of

	Increase for every 100 lb. of nitrogen applied. Grain.	Straw.
Sulphate of ammonia, gave .	$42\frac{1}{2}$ bush.	124 stones
Muriate of ammonia, . .	$52\frac{1}{3}$ ...	176 ...
Nitrate of ammonia, . .	63 ...	205 ...
Nitrate of potash, . . .	196 ...	684 ...
Nitrate of soda, . . .	$55\frac{1}{3}$ ...	240 ...

In the above numbers, also, there is no similarity, so that we are forced to one of two conclusions—either that the experiments are worth nothing, or that the effect of these applications, when made to corn crops, is not determined by the proportions of nitrogen they respectively contain.

3°. In the experiments upon grass made at Barochan, on three different fields, one hundred pounds of nitrogen, in the form of

	Increase for every 100 lb. of nitrogen applied. 1°.	2°.	3°.
Sal-ammoniac, gave	53 stones	$46\frac{1}{3}$ stones	$20\frac{1}{2}$ stones
Sulphate of ammonia,	78 ...	39 ...	30 ...
Nitrate of potash, .	160 ...	119 ...	70 ...
Nitrate of soda, .	113 ...	82 ...	80 ...

Each of these columns represents the effect of a hundred pounds of nitrogen upon the grass of a different field, and there is no more approach to equality among the numbers they respectively contain, than among those by which the effects upon the oat crops were represented above. One might infer from them, however, that the nitrates possess some special virtue independent of the nitrogen they contain.

4°. In Mr Kuhlmann's two experiments upon old meadow grass, 100 kilogrammes of nitrogen, in the form of—

	Increase for 100 kilogrammes of nitrogen.
Sulphate of ammonia, gave . .	6094 kilogrammes.
Nitrate of soda, ...	9232 ......
Nitrate of lime, ...	5143 ......

And, in his second experiment,

Muriate of ammonia gave . . .	7061 ......
Nitrate of soda, ...	8453 ......

Nor, from these experiments, can we venture to say either that like quantities of nitrogen produce like effects in like circumstances, or that the comparative effects which two substances may be expected to produce are to be measured by the proportions of nitrogen they respectively contain.

We may safely admit, I think, that each of the salts of ammonia, and each of the nitrates, exercises a special and peculiar action upon vegetation—that this action is generally a favourable, often a profitable one—and that the action of each of these compounds is probably different in the case of different plants, and is modified, also, by climate, season, soil, locality, and other circumstances. To make out the several special actions of these compounds, and the modifying influence of circumstances, will require many carefully conducted and skilfully contrived experiments.

§ 2.—*Influence of the state of chemical combination in which the nitrogen exists in a substance on its efficacy as a manure. Comparative experiments with gelatine, rape-cake, and sulphate of ammonia, on the weight of the crop.*

The comparative experiments with the salts of ammonia and

with the nitrates—which I have analysed in the preceding section —appear to justify our conclusion that each compound exercises an action special to itself, and to reject the opinion that the proportion of nitrogen in such fertilising substances determines the amount of their sensible action upon the crop.

But we have other experiments also, the results of which tend to establish the general principle that the state of chemical combination in which the nitrogen exists, in any substance, influences very much its sensible effect upon a crop. Gelatine and rape-cake contain nitrogen, the former in large proportion, and both promote vegetation in a striking degree. But the fertilising effect of this nitrogen is materially affected by the state of combination in which it exists in them respectively. This is shown by the results of certain experiments upon turnips detailed in the preceding chapter, p. 193, and to which I refer the reader. It is very distinctly brought out also by three other series of experiments which I shall here introduce.

1°. *With gelatine compared with nitrate of soda and sulphate of ammonia upon grass.* Along with the other substances employed in his experiments upon hay, Kuhlmann tried also the gelatine of bones. This was obtained by boiling bones in the process for extracting the fat, before burning them for the manufacture of animal charcoal. It was applied in the liquid form, at the rate of 500 kilogrammes of the dry gelatine to the hectare, or 4 cwt. per acre. The applications were made in 1844 and 1846, the plots being undressed in 1845. In the following table the results, per hectare, are thrown into a comparative form :—

	Quantity applied in the two years.	Nitrogen per cent in the manure.	Nitrogen applied per hectare.	Increase of hay in the three years.	Increase for 100 kilos. of nitrogen.
Sulphate of ammonia,	500 kilos.	21.2	106 kilos.	3291 kilos.	3105 kilos.
Nitrate of soda, .	500 ...	16.6	83 ...	3827 ...	4610 ...
Nitrate of lime, .	500 ...	17.1	86 ...	2204 ...	2562 ...
Gelatine, . .	1000 ...	17.0	170 ...	4866 ...	2862 ...

The last column shows an approximation among the comparative effects of gelatine, sulphate of ammonia, and nitrate of lime. Whether this indicates a real or only an apparent similarity of action in these substances, must be cleared up by future experiments.

2°. *With rape-cake compared with sulphate of ammonia upon turnips.* Mr Lawes has published the results of comparative experiments with these substances applied singly and together, to a crop of Norfolk white turnips, grown upon his farm in Hertfordshire in 1845. They were as follows. (Rape-cake contains about $4\frac{1}{8}$ per cent of nitrogen.)

	Bulbs.		Tops.		Nitrogen applied per acre.
	tons.	cwt.	tons.	cwt.	lb.
1°. Nothing gave . .	—	$13\frac{1}{2}$	—	$14\frac{1}{4}$	—
2°. Farm-yard manure, 12 tons,	17	—	7	7	—
3°. Rape-cake, 8 cwt. .	4	16	4	5	38
4°. ...... 18 cwt. .	9	$8\frac{1}{2}$	8	9	80
5°. ...... 8 cwt. Sulphate of ammonia, 3 cwt.	5	$8\frac{1}{2}$	4	6	110
6°. Rape-cake, 18 cwt. Sulphate of ammonia, 3 cwt.	8	—	7	18	152
7°. Sulphate of ammonia, 6 cwt.	3	4	1	14	142

a It is interesting to observe how very much larger a proportion of tops, compared with the bulbs, the rape-cake produced than any of the other applications, even than the farm-yard dung.

b But what more particularly concerns our object is the total want of connexion between the comparative weights of tops, or of bulbs, or of both taken together, and those of the nitrogen contained in the different applications. Take, for example, the total weights of the crops, (tops and bulbs,) and the following table shows how much was produced in each experiment by 100 lb. of nitrogen:—

	Total produce.		Total nitrogen applied.	Produce for 100 lb. of nitrogen.	
	tons.	cwt.	lb.	tons.	cwt.
1°.	1	8	—	—	—
2°.	24	7	—	—	—
3°.	9	1	38	23	16
4°.	17	$17\frac{1}{2}$	80	22	7
5°.	9	$14\frac{1}{2}$	110	8	17
6°.	15	18	152	10	$4\frac{1}{2}$
7°.	4	18	142	3	$8\frac{1}{3}$ *

Here we see three things deserving of notice; *first*, that the

* In calculating this column, I have not thought it of consequence to deduct from the produce of the dressed portions the small crop yielded by the part to which nothing was applied.

rape-cake gave a much greater increase, in proportion to the nitrogen it contained, than the sulphate of ammonia; *second*, that the addition of sulphate of ammonia actually diminished the natural effect of the rape-cake in No. 6, compared with No. 4, in both of which cases 18 cwt. of rape-cake were applied; and *third*, that the sensible effects of the rape-cake when used alone in the two experiments, 3 and 4, was nearly in proportion to the quantity applied.

c The opinion entertained by some writers on this branch of science—that the nitrogen contained in rape-eake and other organic substances only becomes valuable or available to plants when it is decomposed and converted into ammonia in the soil or elsewhere—is inconsistent with—we may say, is directly contradicted by—the above experiments. If one hundred pounds of nitrogen, already in the form of ammonia, (in the sulphate of ammonia,) produced in the seventh experiment only 3 tons 8 cwt., while an equal weight, in the form of rape-cake, produced 22 or 23 tons, it is clear that some other virtue yet unrecognised must reside in the constituents of rape-cake. And if in this, similar virtues may reside also in other organic substances, of which nitrogen forms a constituent part.

3°. *With rape-cake, compared with sulphate of ammonia, upon wheat.*—In 1846, Mr Lawes employed these substances in comparative experiments upon wheat (old red Lammas variety) sown upon a piece of exhausted land, to which no manure had been previously applied, with the following results:—

	Grain.		Straw.	Total produce.
	bush.	lb.	lb.	lb.
1°. No manure gave	17½ or	1216	1455	2671
2°. Rape-cake, 4 cwt.	23½ or	1614	2033	3647
3°. Sulphate of ammonia, 2 cwt.	27¼ or	1850	2244	4094
4°. Rape-cake, 4 cwt. Sulphate of ammonia, 2 cwt.	28¾ or	1942	2603	4545

The small comparative effect of the two substances, applied together in the fourth experiment, is striking enough; but the bearing of the whole results upon the influence of the nitrogen will appear more clearly by showing the increase in each case for a hundred pounds of nitrogen in the manure.

	Total nitrogen applied.	Increased produce for 100 lb. of nitrogen. Grain.	Straw.	Total.
	lb.	lb.	lb.	lb.
2°.	19½	2041	2964	5005
3°.	47½	1335	1661	2996
4°.	67	1083	1713	2796

The rape-cake used alone, in the second experiment, gave an increased produce both of grain and straw more than one-half greater in proportion to its nitrogen than the sulphate of ammonia, when applied alone, in the third experiment. And, when the two substances were used together, the produce of grain was still less from a hundred of nitrogen than when the sulphate was used alone.

In so far, therefore, as the experiments detailed in the present section are worthy of reliance—and in the absence of duplicate trials, we must not rely too confidently upon them—it appears that the sensible effect of an organic substance containing nitrogen on the quantity of a crop to which it is applied, is by no means indicated by the proportion of nitrogen it is known to contain. We saw reason in the preceding section to conclude that such was the case, also, with the salts of ammonia when compared with each other, and with the nitrates compared among themselves, or with the salts of ammonia. It is, therefore, probable that every substance which contains nitrogen exercises upon growing plants an action peculiar to itself in quality and in intensity. The nature and amount of this special action can only be made clear by further experiments specially directed to this end.

§ 3.—*Influence of the quantity of nitrogen, and of the state of chemical combination in which it exists in a fertilising substance, on the quality of the crop to which it has been applied.*

But if the quantity of a crop is not directly as that of nitrogen in the manure, is not the quality determined by the amount of nitrogen applied to the land? This opinion was formerly entertained, but it will not bear the test of rigorous investigation. I have elsewhere discussed this subject;* but some

* *Lectures on Agricultural Chemistry*, 2d edition, p. 874.

experiments of Mr Lawes, similar to those described and discussed in the previous sections, throw some additional light upon it.

1°. *Experiments upon turnips.*—He drilled in certain mineral manures with the seed over the whole field; he then top-dressed different parts of it with rape-dust, sulphate of ammonia, and a mixture of the two. When the crop was gathered, the proportion of nitrogen in the turnips grown upon each plot was determined as nearly as possible by repeated analyses. The numbers in the following table represent the total produce, and the percentage of nitrogen in the dry turnip bulbs, produced by the aid of the different manures:—

Drilled Manures.	Drilled manures only.	Drilled and top-dressed with 10 cwt. of rape-cake.	Drilled and top-dressed with 3 cwt. sulphate of ammonia.	Drilled and top-dressed with 10 cwt. rape-dust and 3 cwt. sulphate of ammonia.
	tons. cwt.	tons. cwt.	tons. cwt.	tons. cwt.
1°. Calcined bones, 400 lb., dissolved in muriatic acid,—				
Total produce, tops and bulbs,	13 15	13 19	13 16	13 5
Nitrogen, per cent, in dry bulbs,	1.46	1.93	2.82	2.22
2°. Superphosphate of lime, 11 cwt.,—				
Total produce, ...	17 1	20 9	16 9	19 18
Nitrogen, per cent, in dry bulbs,	1.58	1.89	2.89	2.44
Nitrogen applied per acre, .	none.	42 lb.	71 lb.	113 lb.

a The last line of this table, compared with the first and third, shows that the proportions of nitrogen applied had no sensible relation whatever to the total weights of the crops produced. This agrees with the deduction we drew in the preceding section.

b As to the quality of the crop, as indicated by the proportion of nitrogen in the bulbs, it appears that it increased in all the experiments till the quantity of nitrogen per acre reached 71 lb., but that it diminished when the quantity amounted to 113 lb. per acre. Still, the increase in the two cases—when 42 and 71 lb. were applied respectively—was by no means in proportion to the quantity of nitrogen applied.

All we can safely infer, therefore, from these experiments is, that substances containing nitrogen, even when they add nothing to the weight of the turnip crop, may improve its quality by

adding largely to the proportion of nitrogen contained in the bulbs. According to what law this increase takes place, or whether, as in the case before us, nitrogen in the form of ammonia improves the quality more than it does in the form in which it exists in rape-cake or other organic substances—these are points which can only be made out by further experimental investigation.

2°. *Experiments upon wheat.* In 1844, Mr Lawes top-dressed one portion of his wheat with superphosphate of lime and another with ammoniacal salts, and in the dried grain reaped from the two plots, he found the percentage of nitrogen to be, from the

Superphosphate of lime, . . .	3.03 per cent.
Ammoniacal salts, ...	2.65 ... *

From which it would appear that the application of the ammoniacal manure had diminished instead of increasing the proportion of nitrogen in the grain.

Again, in 1846, he caused the percentage of nitrogen to be determined in the grain reaped from experimental plots to which he had applied respectively rape-cake, sulphate of ammonia, and a mixture of the two. A general view of his results is presented in the following table :—

Kind of manure applied.	Total produce of grain.	Total nitrogen applied per acre.	Nitrogen per cent in the grain.
No manure, . . .	17½ bush.	... lb.	1.95
Rape-cake, 4 cwt., . .	23½ ...	19½	1.85
Sulphate of ammonia, 2 cwt.,	27¼ ...	47½	2.01
Rape-cake, 4 cwt., . . Sulphate of ammonia, 2 cwt.,	28¾ ...	67	1.93

Here, though the crop was increased—not, however, in proportion to the nitrogen applied—the nutritive quality, as indicated by the percentage of nitrogen, may be considered to have been sensibly the same throughout. The numbers show a slight diminution of nitrogen in the rape-cake grain, and a slight increase in that top-dressed with sulphate of ammonia, but the

* See *Royal Agricultural Journal,* viii., p. 235 and 248.

differences are small enough to be within the limits of the ordinary errors of analyses.

On the whole, therefore, it would appear, from the experiments detailed in this section—

1°. That the nutritive quality, as indicated by the proportion of nitrogen, may be increased in the bulbs of turnips, and probably in other roots, by the use of manures rich in nitrogen—though what relation the increase bears to the quantity of nitrogen applied, or to its state of chemical combination, does not appear.

2°. That manures containing nitrogen do not sensibly augment the proportion of nitrogen in the grain of wheat crops to which they have been applied. In some cases they rather appear to diminish it.

It is to be remembered, however, that there is a great difficulty in ascertaining the average chemical composition, especially of a crop of turnips or other roots; and therefore *that*, for this and other reasons, our confidence in the above conclusions ought not as yet to be very decided.

§ 4.—*Suggestions for experiments with the carbonate, nitrate, muriate, and sulphate of ammonia.*

A perusal of the experimental results embodied in this and in the preceding chapter must already have suggested, both to the theoretical and to the practical reader, many interesting comparative trials with the salts of ammonia. I shall put down here, however, such as appear to me, in the present state of our knowledge, to be most important.

1°. It is desirable to ascertain more correctly the comparative influence of the different salts of ammonia, applied in equivalent quantities to the same crop, in the same circumstances.

Of course, this means that the crop experimented upon should be varied until the comparative effects of all these salts on each of our usually cultivated crops is ascertained.

2°. With the same salt applied in different quantities at different times—all at once, and in successive portions at successive periods. Does the produce increase directly with the

quantity applied? Is it influenced by the time of applying it, by the weather, by the soil, &c.?

3°. Is the sulphate most favourable to leguminous crops, as other sulphates are supposed to be? Are the onion and the cabbage especially influenced by it?

4°. To the scientific agriculturist, the nitrate and the muriate may be especially commended. Do they equally favour any given crop? Are their actions equally affected by dark and by bright or sunny weather? Does the nitrate or the sulphate more especially demand the presence of the sun?

5°. Are their effects always more favourable on light and open than upon stiff clay soils? May they not be profitably used on all young crops on any soil, when the crops are yellow, sickly, and stunted in their growth?

6°. Are they especially indicated for use on *deaf* soils, or such as contain much inert vegetable matter—on such as are poor in organic matter—on soils newly trenched or turned up from a depth, and so on?

7°. Can they be used with safety for any and for what crops, on soils which have already a tendency to produce a large growth of straw or of tops?

8°. Is a crop of any kind increased by different doses of the same salt, in proportion to the quantity of nitrogen applied? Are the comparative effects of two different salts directly or otherwise proportional to the quantity of nitrogen they severally contain? If not generally, is this the case in regard to any one crop in any given circumstances? These questions have been discussed in the preceding sections, and all the field results we at present possess seem to answer both questions in the negative.

9°. The nitrogen in the nitrate of ammonia is in two states—partly in that of nitric acid, partly in that of ammonia. Are both these forms of nitrogen equally efficacious in this or that circumstance—of soil, weather, plant, or period of growth? Will a nitrate of potash, soda, or lime, which contains as much nitric acid as the nitrate of ammonia, produce an equal effect with this salt of ammonia upon any plant in any circumstances? Will a sulphate or muriate of ammonia, containing as much

ammonia as the nitrate of ammonia, produce an equal effect? These are curious questions, neither of which will probably be answered in the affirmative when careful field experiments are made, but the investigation of them may conduct us to important practical truths.

10°. Do the salts of ammonia add to the nutritive quality of a crop? This question is to be solved by experiments in feeding with the crops raised by means of the salts of ammonia, and by analysing them in the laboratory. The former method is in the power of the practical man and is deserving of much attention.

This general question includes several subordinate ones, such as—

a Do they add to the richness of grain in gluten, as some have said? This we have elsewhere seen to be very doubtful; but the question is by no means decided.

b Do they increase the feeding quality of root-crops and cabbages? The comparative feeding quality is represented pretty nearly by the proportion of nitrogen contained in the crops we raise, and this proportion appears capable of material increase by the use of the salts of ammonia, and of rape-cake. The details of Mr Lawes' experiments upon two crops have been given in a preceding section.

c Is the more succulent grass of fields, top-dressed with salts of ammonia, more nutritious also, weight for weight? This is a question which the feeder, as well as the chemist, is required to solve.

d As to the function of the ammonia, does it directly supply nitrogen to the crop at all, or does it act in some other way? This question is more purely theoretical, though of great practical consequence.

11°. In conclusion, I may suggest the importance of comparative experiments between the nitrates of potash, &c., and any of the salts of ammonia. If they be applied in equivalent quantities, or two equivalents of the one against a single equivalent of the other, accurate duplicate experiments made upon any crop will afford valuable data for the solution of existing theoretical and practical difficulties.

§ 5.—*Suggestions for experiments with the acetate, oxalate, and humate of ammonia.*

The composition of these three salts has been given in the first section of the preceding chapter.

1°. *Acetate.* The acetate of ammonia has been said to be poisonous to growing plants. The same has also been stated by Bouchardat of the carbonate, sulphate, muriate, &c. But extended experience in this country has shown the latter to be incorrect. It would be interesting, therefore—it is necessary, in fact, to the satisfactory clearing up of this point—that experiments should be made with the view of ascertaining the special nature and the extent of the action, of the acetate, compared with that of equivalent quantities of the other salts of ammonia.

2°. *Oxalate.* As the oxalic acid occurs abundantly in plants, it is desirable that its influence upon their growth should be ascertained. Though, in the first instance, this is a theoretical inquiry, yet it is not without a practical bearing.

Certain soils produce the sorrels (*Rumex acetosa and acetosella*) in large quantities, and the addition of lime to such soils extirpates these plants. Does oxalic acid exist in such soils? will the application of a soluble oxalate favour the growth of those plants in which oxalic acid is found or formed in any considerable quantity? How will the ammonia and the oxalic acid contained in oxalate of ammonia modify the action of each other?

With the view of obtaining answers to these questions, it would be desirable to institute comparative duplicate experiments with the carbonate of ammonia, with oxalic acid, and with oxalate of ammonia. For though, where there is lime in the soil, the oxalic acid would probably unite with it to form the insoluble oxalate of lime, before it had an opportunity of entering into the roots of plants, still it may not be incapable, even in that state of combination, of modifying the plant's growth, and of throwing light upon the nature of its chemical influence upon vegetation.

3°. The *humate.* It is a disputed point at present among chemical physiologists how far the dark-coloured acid substances (the humic and ulmic acids) contained in the soil contribute

directly to the growth of plants. It cannot be doubted that the largest proportion of the organic matter of the soil is derived from the air, through the instrumentality of vegetables that have lived and died upon it. But does this organic part of the soil serve no direct purpose in feeding and nourishing the plant? That it should do so is quite consistent with the fact of the plant's drawing a large proportion of its carbon from the air. But this question would be helped towards a satisfactory solution if experiments were made.

a With carbonate of ammonia in different proportions, applied in different ways, and under different circumstances.

b With humate of ammonia alone, and in comparison with the carbonate of ammonia, upon the same crops, and in the same circumstances. These would show whether and to what extent the humic acid modified the action of the ammonia.

c With humate, in comparison with sulphate or muriate of ammonia. These would show how far the mineral sulphuric or muriatic acid acted in a similar way with the humic acid—how far the presence of the organic acid did or did not promote the more rapid and healthy growth of the plant.

Though the results obtained by means of these comparative experiments may not be wholly free from doubt and ambiguity, yet they will form a valuable basis for future field inquiries.

§ 6.—*Suggestions for experiments with the phosphate of ammonia, with the ammoniacal phosphate of soda, and with the ammoniacal phosphate of magnesia.*

1°. The *phosphate of ammonia* described in the preceding chapter is likely to prove a very powerfully fertilising substance. Being capable of supplying both nitrogen and phosphorus to the plant, it may be expected to produce a very sensible action upon its growth; and as it may be manufactured easily, it is desirable that field experiments should be tried with it applied alone.

a In different proportions, at different seasons, and to different plants.

b In comparison with the other salts of ammonia, and especially with the sulphate, under similar circumstances.

The reason for particularly specifying the sulphate, is that the sulphuric acid possesses many properties which approach to those of the phosphoric acid, and may, therefore, in the interior of the plant, perform chemical functions of a similar kind.

The phosphate of ammonia is not here recommended for the first time. It has already been tried, along with other substances, by Mr Lawes, on the turnip crop of 1844, as follows:—

No manure gave, of bulbs, . . .	2 tons 4 cwt.
Farm-yard manure, 12 tons, . . .	10 ... 15 ...
Superphosphate of lime, 4 cwt., . . Phosphate of ammonia, 56 lb., . .	6 ... 18 ...
Superphosphate of lime, 4 cwt., . . Sulphate of ammonia, 56 lb., . .	5 ... 10 ...
Superphosphate of lime, 4 cwt., . . Rape-cake, 4 cwt., ...	7 ... 0 ...*

As we have no experiment with the superphosphate applied alone, the above results—if we may rely upon crops of bulbs, which are so very small—merely indicate that the phosphate of ammonia, under the circumstances, produced an effect about equal to that of eight times its weight of rape-dust, and something greater than that of its own weight of sulphate of ammonia. They urge as strongly, however, to further more comparative and duplicate experiments with these several substances applied alone.

2°. *Ammoniacal phosphate of soda.*—This salt is formed by dissolving together in hot water six or seven parts of the common phosphate of soda of the shops with one of sal-ammoniac, and setting the solution aside to cool. It crystallises in large transparent prisms, which possess a cooling saline taste, effloresce slightly in the air with loss of ammonia, and dissolve readily in water. They consist of—

Ammonia, ...	8.11 per cent.
Soda, ...	14.89 ...
Phosphoric acid, ...	34.06 ...
Water, ...	42.94 ...
	100

The equivalent weight of this salt is 262.

The presence, in this compound, of ammonia, soda, and

* *Journal of the Royal Agricultural Society*, vol. viii. p. 510.

phosphoric acid, three substances very necessary to plants, make it desirable to ascertain, by comparative trials, its special effects upon vegetation.

a Alone, applied in different quantities under different circumstances, to different crops, and on different soils.

b In comparison with the several substances of which it consists, with the view of eliminating, as far as possible, the special effects or influence of each. In these experiments, the effects produced respectively by the carbonate of ammonia, the phosphate of ammonia, the carbonate of soda, and the phosphate of soda, on separate portions of the same field and crop, if carefully observed and noted, would afford us the means of drawing very probable deductions.

3°. *The ammoniacal phosphate of magnesia* is produced during the fermentation of human urine, and falls as a white crystalline powder when a solution of sulphate of magnesia is mixed with one of phosphate of ammonia, or of the ammoniacal phosphate of soda. It is sparingly soluble in water, and consists of—

Ammonia,	6.9	per cent.
Magnesia,	16.3	...
Phosphoric acid,	29.1	...
Water,	47.7	...
	100	

Its equivalent number is 307.

All the constituents of this salt are necessary to the growth of plants. Independently of any supposed special action of the salt as a chemical compound, there is reason, therefore, to anticipate very striking effects from its application to growing plants. This anticipation has been so far verified by an experiment of M. Boussingault. He treated young plants of maize with this substance, to the extent of about half-an-ounce for each plant, and found that not only did they grow faster and larger, but that, while plants to which no phosphate had been applied produced one perfect and one abortive head, those which had been treated with it produced two perfect and one abortive head, and the grains were also double those of the others in size. This encouraging result suggests the propriety of further and more enlarged experiments.

a On corn-crops of different kinds, under different circumstances, and applied in different quantities.

b On root-crops, and especially on the potato, for which salts containing magnesia are alleged by some to be specially adapted.

c In comparison with equivalent quantities of carbonate of ammonia, carbonate or sulphate of magnesia, and phosphate of ammonia. These comparative trials will throw some light on the part which is performed by each of the constituents in bringing about the result which the compound salt is observed to produce.

§ 7.—*Suggestions for experiments with gelatine, oil-cakes, urea, nitrate of urea, and uric acid.*

In connexion with the salts of ammonia and the nitrates, I would suggest experiments with certain other substances containing nitrogen, the special and comparative action of which upon growing plants it is desirable to ascertain. I would especially recommend gelatine, the organic or soluble part of bones, —rape and other cakes, left by the oily seeds when crushed in the oil-mills,—urea, a peculiar substance existing in urine to the amount of about 3 per cent,—uric acid, a substance also existing in urine, but in much smaller proportion,—and the nitrate of urea, a crystalline compound which is obtained by evaporating urine to a very small bulk, and adding nitric acid to the concentrated liquor.

These substances contain nitrogen in the following proportions:—

Gelatine contains . . .	17	per cent of nitrogen.	
Urea, ...	46.7	...	...
Uric acid, ...	34½	...	...
Nitrate of urea, . . .	36.9	...	...
Oil-cakes, ...	4 to 4½	...	...

The purposes for which experiments with these substances may be made, are—

1°. To ascertain the special action of each upon any given crop, when applied in different quantities, and under different circumstances.

2°. To determine whether their respective sensible effects are in proportion to the quantity of each applied, when different doses are used; and whether they are directly as, or have any relation to, the proportions of nitrogen they respectively contain.

3°. Whether their action is in any way different from that of the salts of ammonia or the nitrates when applied in quantities containing the same weights of nitrogen, and whether the difference, if any, is the same in the case of all crops.

4°. In comparing these substances with the salts of ammonia, it should be recollected that urea readily decomposes and becomes converted into carbonate of ammonia. This decomposition is very likely to happen when urea is mixed with the soil, and therefore its action may be very analogous to that of carbonate of ammonia. The purpose, therefore, of comparative experiments between urea and this carbonate is to ascertain how far the peculiar form of combination of nitrogen in each affects its action upon the plant.

5°. Again, one-third of the nitrogen in the nitrate of urea exists in this compound in the state of nitric acid. This nitrate, therefore, may exercise an action not unlike that of the nitrate of ammonia, with which it would be interesting to compare it.

We have, in fact, in regard to urea, these several questions to ask—

a Does urea produce an effect similar or equal to that of ammonia, when the quantities of each applied contain equal weights of nitrogen?

b Does nitrate of urea act differently in any way from urea, when equal quantities of nitrogen are applied? What influence upon the result has the circumstance that one half of the nitrogen in the nitrate of urea is in the form of nitric acid, and the other half in the form of urea?

c What is the effect of nitrate of ammonia compared with nitrate of urea? In both, one half of the nitrogen is in the state of nitric acid, the other half in that of urea or of ammonia.

These questions indicate the purposes for which the experiments are to be made, and the search for answers to them must be very interesting.

6°. The chief interest which attaches to experiments with uric acid arises from the circumstance, that while, in man, the nitrogen separated from the system by the urine escapes chiefly in the state of urea, which readily decomposes, birds, serpents, and insects void it in the state of uric acid, which is a much more stable compound. This is one reason why the urine of man so readily produces ammonia, and why the excretions of birds are more capable of lengthened preservation.* Our natural guanos owe to this cause their richness in ammoniacal matter, and it will be very useful to know, whether or not plants can directly avail themselves of uric acid without previous fermentation or decomposition. We cannot ask such experiments at the hands of the practical farmer, but there are many at whose command uric acid, artificially prepared or excreted by serpents, may be in sufficient quantity to admit of its being employed for experiments upon vegetation.

7°. The experiments of Kuhlmann and Lawes, made with rape-dust and with gelatine, of which an account has been given in the early part of this chapter, suggest various inquiries, which the experimenter will desire to answer by his trials with these substances, such as—

a Do gelatine, sulphate of ammonia, and nitrate of lime, applied in quantities containing equal weights of nitrogen, always approximate in their effects, as in Kuhlmann's experiment upon hay, and are they always surpassed by nitrate of soda?

b Do rape and other cakes generally produce a greater comparative effect upon turnips than the sulphate of ammonia does, in proportion to the nitrogen they contain, as in Mr Lawes' experiment, or a smaller effect, as in Mr Fleming's (p. 193)?

* The relative composition of urea and uric acid is as follows:—

	Urea.	Uric acid.
Carbon,	20.0	37.15
Hydrogen,	6.6	2.49
Nitrogen,	46.7	34.66
Oxygen,	26.7	25.70
	100.	100.

In twenty-four hours, a full-grown man voids about 270 grains of urea, and only about 8 grains of uric acid.

c Independently of their effect upon the quantity, what influence do they respectively exercise on the quality of the crop? Is the proportion of nitrogen in the grain of wheat, or in the bulb of the turnip, increased or decreased by the use of these substances, or by uric acid and the nitrate of urea? Is the increase or decrease equal to, or does it bear any relation to that caused by the salts of ammonia, or by the nitrates?

d Does the proportion of carbon with which the nitrogen is associated in urea, uric acid, or oil-cakes, bear any relation to the differences in their effects as compared with those of ammonia or its salts?

A careful perusal of the introductory sections of the present chapter will cause the thinking field-experimenter and chemical analyst to ask himself many other such questions as these.

CHAPTER XIV.

Experiments with lime. General functions performed by lime in the soil and in the plant. Natural differences of composition among limes and limestones. Suggestions for experiments with crushed limestone. Suggestions for experiments with different chalks and marls. Results of experiments with quick-lime applied alone to land preparing for wheat. Suggestions for experiments with silicate of lime, and with burned limes which contain it. Suggestions for experiments with magnesia, and with limes which contain it in considerable proportions.

THE numerous experiments which practical men, in such climates as ours, are constantly making on the use of lime in agriculture, as well as the great economical importance of this substance as an improver of the land, would sufficiently justify me in making it a separate subject of consideration in connexion with these suggestions. But there are, in reality, many points in reference to the use of lime, upon which much obscurity rests, and over which carefully conducted experiments may throw much light.

Those who have read the small work I have recently published on the use of lime,* may have already anticipated some of the experimental suggestions contained in this and the succeeding chapter. For the sake of those, however, into whose hands that work may not come, and with the view of making the present more complete, I shall advert to the several points in regard to which experiments are likely at present to be most interesting or most profitable.

§ 1.—*General functions performed by lime in the soil and in the plant.*

In performing experiments with a view to pecuniary profit,

* *The Use of Lime in Agriculture.* Blackwood: 1849.

it is of much advantage to possess a general idea of the functions it performs in the soil or in the plant. We have stated, in fact, that one of the objects we have in view, in our more strictly scientific experiments, is to throw light upon the nature of these functions, with a view to the ultimate profit of the practical man.

The functions which lime performs in the soil, though chiefly chemical, are also in part mechanical. It consolidates light sandy soils,* and generally opens such as are heavy and difficult to work; but along with this mechanical, it always performs important chemical functions.

1°. It directly neutralises such acid substances as already exist in the soil; and, being usually added in larger quantity than is necessary for this purpose, it is ready to unite with new acid compounds which may be formed.

2°. It promotes the decomposition of the organic and mineral constituents of the soil, so as to prepare them for more readily ministering to the wants of the plant. Among other benefits which are supposed to result from this chemical action, are the liberation of alkaline matter from the rocky fragments which exist in the soil, and the production of nitrates from its organic part.

3°. To the plant it supplies the lime so necessary to the production of its several parts; and either as a carrier of other kinds of food, or as a promoter of chemical changes within it, lime, without doubt, performs other duties we are as yet unable to specify.

One common error in regard to the functions of lime the experimenter should bear in mind. Lime will in many places promote the growth of plants, but it will not anywhere serve the purposes of other manure, or render ordinary manuring unnecessary. Hence the reason why so much injury has in

* This practice is very ancient. Thus Columella says,—"Si tamen nullum genus stercoris suppetet, ei multum proderit fecisse quod M. Columellam patruum meum, doctissimum et diligentissimum agricolam, sæpe numero usurpasse memoriæ repeto, ut *sabulosis locis cretam* ingeret, cretosis ac nimium densis sabulum; atque ita non solum segetes laetas excitaret, verum etiam pulcherrimas vineas efficeret."—*De Re Rusticâ*, lib. ii., cap. 16.

many instances been done by the long-continued and indiscriminate use of lime. Hence also the term *stimulant* applied to lime, as if it only, by some sort of compulsion, urged on the soil or the plant to increased activity.

In reality, the results of the action of lime resemble those of many other substances which cause the materials of the soil to become available to plants, or the plants to avail themselves more fully of what the soil contains.

The sulphate and muriate of ammonia, for example, acted in this way in some experiments of Mr Lawes. He sowed wheat during three successive years on the same piece of land, and to the crops of the two last years applied only the salts of ammonia, with the following results:—

	Manure applied.	Produce reaped.	
		Grain.	Straw.
1844.	Superphosphate of lime, 5 cwt., Silicate of potash, 220 lb.,	16 bush.	1112 lb.
1845.	Sulphate and muriate of ammonia, each 1½ cwt.,	31¾ ...	4266 ...
1846.	Sulphate of ammonia,	27⅓ ...	2244 ...

Now, though the special action of lime is very different from that of the salts of ammonia, yet an increase such as the above, in 1845 and 1846, might have been the consequence of its application to the land. But neither the lime nor the salts of ammonia, if applied year by year, would alone suffice to keep up these increased returns. In our crops we take out of the land what neither of these applications restore, and it must, therefore, inevitably be sooner or later exhausted.

§ 2.—*Natural differences of composition among limes and limestones.*

Limes and limestones vary in composition often in a very sensible degree. Even when the differences are comparatively small, the large quantities of lime which are usually laid on the land causes a very considerable difference, on the whole, in the nature of the application.

The natural differences affect chiefly the proportions of siliceous or earthy matter, of magnesia, of sulphur, and of phos-

phoric acid. Limestones also contain minute quantities of soda—probably, in the state of common salt, derived from the salt water of the sea, in which most of our limestones were deposited—and perhaps also of potash; but no experiments have yet been made to determine either the proportion of this alkaline matter, or the extent to which that proportion varies in different limestones.

1°. *The siliceous, or earthy matter*, varies from one to forty per cent of the weight of the limestone. When the quantity is very large, the lime, after burning, does not slake or fall to powder on the addition of water. Such limes, after being burned, are usually crushed by machinery, and are then used as cements. They set or harden almost immediately when mixed with water, but are never employed for agricultural purposes.

When a limestone containing silica is burned in a kiln, the silica combines with a portion of the caustic lime, and forms silicate of lime. The presence of this silicate must modify the action of the lime upon the land to which it is applied; and the extent of the modification must be commensurate with the proportion of siliceous matter which the limestone originally contained. In what way, or to what extent, the silicate of lime modifies the special action of the caustic lime, has not as yet been made the subject of experiment.

2°. *Magnesia* exists in nearly all limestones in greater or less proportion. Good agricultural limes rarely contain more than five per cent; but in what are called magnesian limes, or dolomites, the magnesia sometimes forms as much as one-half of the whole weight. Such limes are usually considered to be injurious to the land. They are said to be too caustic, to burn it up, and to destroy the crops. Precise experiments, made upon different crops, are much wanted to bring out clearly the special action of the magnesian ingredient of these limes, and to what extent it may be safely applied to given crops and soils.

3°. *Sulphur* exists in all our limes in minute quantity in the state of sulphuric acid, forming with the lime sulphate of lime or gypsum. The quantity, so far as analyses have yet been made, varies from one-third of a per cent to one per cent of

the weight of the limestone. Future research will probably show it to be in many cases much greater than this. In burned limes the quantity of gypsum is almost invariably greater than in the native limestones. The iron pyrites (sulphuret of iron) which exists in nearly all limestones, and contaminates the greater number of our coals, is decomposed in the lime-kiln, and its sulphur combines in great part with the burning lime. And when it is considered that inferior coals, often abounding in sulphur, are generally employed in the burning of lime, it will be understood that the proportion of gypsum contained in burned lime must always be considerably greater than in the unburned limestones.

Gypsum is known especially to favour the growth of certain crops. It acts differently from common quicklime. Its presence, even in small proportion, in a large application of lime cannot therefore be without effect upon the future crops. And a lime which contains very little gypsum must, from this cause, act differently from one which contains comparatively much. This is a source of difference in the mode of action and visible effects of limes and limestones from different districts, which has not hitherto been made the subject of experiment.

4°. *Phosphorus*, or phosphoric acid in the state of phosphate of lime, exists in all limestones and burned limes in minute but variable quantity. From one-third of a per cent to two per cent are the limits between which in burned limes the proportion of phosphate of lime usually varies, according to our present researches. But, though small, these quantities are sufficient to produce an important influence upon the soil to which the limes that contain them are applied. A ton of lime, in which the phosphate of lime exists in the proportion of one-third of a per cent or of two per cent respectively, contains—

	When the proportion is	
	⅓ per cent.	2 per cent.
Phosphate in a ton of the lime, .	7½ lb.	45 lb.
Equal, in common bone-dust, to .	15 ...	90 ...

Every ton of lime in the one case, therefore, carries with it as much of the phosphates as is contained in 15, and in the other case as is contained in 90 lb. of bone-dust. If five tons

of these different varieties of lime be applied, which is a moderate dose, the one gives to the land the phosphate of about ten bushels, the other of about a bushel and a half, of bones. It is obvious, therefore, not only that the fertilising action of the lime which contains the larger quantity must be modified in a considerable degree by the presence of the phosphate, but that the sensible effects of the two different limes must differ with the quantities of this compound which they respectively contain.

The following tables exhibit the composition of four varieties from the carboniferous limestones of Cumberland, Dumfries, and Lanark, respectively, in their natural or unburned, and in their burned states. They were analysed in the burned state, as they are represented in the second table; I have been unable, therefore, to distinguish between the gypsum existing naturally in the limestone and that which was formed during the burning in the kiln.

a Composition of the limestones :—

	Cockermouth.	Brampton.	Kilnhead.	Carluke.
Carbonate of lime, .	94.86	94.71	95.89	93.91
Sulphate of lime, . .	0.23	0.32	0.32	0.85
Phosphate of lime, . .	?	0.33	?	1.14
Carbonate of magnesia, .	1.26	2.32	0.54	2.06
Alumina and oxides of iron,	0.73	1.03	1.20	1.63
Silica, ...	2.92	1.29	2.05	0.41
	100	100	100	100

b Composition of the burned limes :—

	Cockermouth, Cumberland.	Brampton,	Kilnhead, Dumfries.	Carluke, Lanark.
Lime, ...	89.77	89.53	88.64	89.78
Sulphate of lime, . .	0.38	0.51	0.51	1.45
Phosphate of lime, . .	?	0.33	?	1.93
Magnesia, ...	1.02	1.88	0.43	1.69
Alumina and oxides of iron,	1.23	1 84	1.98	2.76
Silica, in the state of silicate,	4.92	2.16	3.39	0.70
Carbonic acid and moisture,	2.68	3.75	5.05	1.69
	100	100	100	100

The limes, of which the latter table represents the composition, differ not only in the proportion of caustic lime they respectively contain, but also in that of gypsum and of phosphate

of lime. These differences throw much light on the cause of the preference which, in every district, practical men are found to give to one lime over another for this or that kind of soil. A knowledge of these chemical differences not only suggests experiments with the view of testing such opinions of practical men, or of putting to the proof the deductions to which the analyses point, but it teaches us also what to look for among the effects they produce, and to make our experiments with a definite end.

§ 3.—*Suggestions for experiments with crushed limestone.*

Marls, limestone gravels, corals, and shell sands, are all known to be useful applications to the soil, and to be very economical where they plentifully occur. Crushed limestone ought to act in a similar way, and to be similarly useful. As, therefore, the full fertility of the land in our climate is not to be brought out without the use of lime in some form, I would suggest that trials should be made with limestones artificially crushed, where circumstances render the burning of them either difficult or unprofitable.

There are two cases in which the crushing of limestone may be recommended ;—

1°. Where the expense of fuel is so great as to render it impossible to burn lime profitably.

2°. Where the limestones are of so impure a quality, or so full of earthy and siliceous matter, as to refuse to slake after they are burned. In this case they are at present considered unfit for agricultural purposes, though many of them, when burned and crushed, are employed as cements. But if crushed by mechanical means, a limestone that is fit for no other purpose may be applied with advantage to the land. Such limestones occur in many districts which at present are supposed to possess no available agricultural lime. The adoption of this method of crushing in those districts might place within the reach of practical men a means of agricultural improvement of which they have hitherto been unable to avail themselves.

Two circumstances ought generally to conspire in order that

this mechanical crushing may be economically adopted. The limestone to be crushed, and water-power to set the crushers in motion, ought to be near each other, that the cost of transport may be avoided. In many hilly and mountainous districts this is the case, and in such localities the method is worthy of a trial.

§ 4.—*Suggestions for comparative experiments with different chalks and marls.*

1°. *Chalks.*—It is a matter of extensive local observation, that the upper and under beds of chalk possess different agricultural virtues.* So much is this the case, that farmers will bring the latter from a great distance, while the former abounds on their own farms. The reason of this has never been satisfactorily explained. I do not find it anywhere distinctly stated either what are the differences in the qualities and composition of the chalks, or in the sensible effects which they severally produce. Do they differ in the quantities of earthy matter, or in the proportions of phosphate of lime, or of other fertilising ingredients they respectively contain? Are their effects mechanically different only? Does the one consolidate or open the soil more than the other, and are they, on this account, preferred respectively according as the soil is light or heavy? Does the one fall under the winter's frost more readily than the other, and does it thus mix more thoroughly with the soil?

I would suggest that some careful observer should apply to the same land, in equal quantities, the two kinds of chalk—that the different effects should be specially noted from year to year—that their effects on unlike soils should be personally observed, or where different kinds of cropping are followed—and that a rigorous analysis of the kinds of chalk employed should be obtained at the same time. By this course of procedure, some light would be thrown upon what is at present incapable of a rational explanation.

2°. *Marls* differ in value, in the estimation of practical men, no less than chalks and limestones. I would here, however,

* See *Use of Lime in Agriculture*, p. 28; and JOHNSTON'S *Elements of Agricultural Chemistry*, 4th edition, p. 85.

draw the especial attention of my readers to the occurrence of phosphate of lime, in sensible quantity, in many marls, the presence of which ought to render them much more valuable as applications to the land. In the marls of the green sand, Mr Nesbit, Mr Payne, and Mr Way, have found this phosphate to exist sometimes to the amount of 14 per cent.; and Mr Payne, who is an extensive and skilful hop-grower, pronounces these marls to be possessed, when applied to his land, of highly fertilising qualities.

The suggestion I would make on this subject, therefore, is, that the existence of phosphate of lime in marl beds should be more generally sought for; and that the value of such marls, when the quantity of phosphate amounts to two or three per cent, should be carefully tested by experiment. Such marls, though comparatively poor in lime, may be very economical applications to the land, even where rich chalks and limestones are readily accessible. They may promote the growth of corn, may give an excellent quality of grain, may maintain the fertility of the land without the use of bones, and may cause bones when applied to produce a less sensible effect than they are usually seen to do.

Thus, while the discovery and use of marls of this kind may prove a source of public advantage and of individual gain, it will also aid the progress of scientific agriculture, by spreading a knowledge of the principles on which the fertilising qualities of different substances depend, and by affording a key to discordant results which often perplex the farmer.

The value of marls, the practical man will learn, is not always to be measured merely by the percentage of lime they contain. If two marls produce different effects, the difference may, in all likelihood, be traced to a difference in composition. If they diminish the after-action of bones, it must be that they contain ingredients which are capable of producing some of the effects which usually follow from the application of this manure. The ingredient they are most likely to contain is the phosphate of lime. This, therefore, should be sought for, and its quantity ascertained.

§ 5.—*Result of an experiment with quicklime, applied alone to land preparing for wheat.*

Notwithstanding the very great extent to which lime is used by the farmers of this country, it is a curious circumstance that we have few or no precise descriptions of the general or special effects it has produced on particular soils or crops; and scarcely any comparative numerical details as to the weights of successive crops raised on limed and unlimed portions of the same soil. To the scientific agriculturist few wants are more serious. However anxious to form a true opinion of the mode of action of a substance, he finds no data on which he can rely. He can neither test the opinions of others, form a safe opinion for himself, nor reasonably recommend to the practical man how, when, or where the substance ought to be applied.

The following experiment by Mr Caird, made at Baldoon, in Wigtonshire, in 1844, I prize the more, as it is the only one of the kind I am able to present to my readers.

The soil was a deep alluvial clay, uniform in quality to a great depth, being what is locally called *carse* land, and contained rather less than one per cent of carbonate of lime. After being slaked, the lime was scattered over the surface in the state of a fine powder, and was ploughed in with a light seed furrow immediately before the seed was sown. The field consisted of six acres—every alternate acre of which was dressed with lime, the other three being left unlimed, as appears in the following table of results:—

	Grain.	Straw.
Quicklime, 300 bushels, gave	43 bushels.	2 tons 5½ cwt.
Nothing, ...	44 ...	2 ... 2½ ...
Quicklime, 240 bushels, .	42 ...	— —
Nothing, ...	40 ...	— —
Quicklime, 180 bushels, .	47 ...	— —
Nothing, ...	43 ...	— —

There was a considerable increase of straw on each of the limed acres, though it was only weighed in the first case. From the three acres there was, on the whole, an increased produce of only five bushels of grain, which was a mere nothing compared

with the expense of the application. But lime is not so immediate in its action upon corn as upon green crops, and its full influence only becomes perceptible after a series of years. This experiment of Mr Caird's ought, therefore, to have been continued—the crops on the several acres being weighed during the succeeding four or five years. In this way only can the true effects, economical and theoretical, of lime be made out, and data be obtained on which we can safely reason and rely. Time and trouble, it is true, are involved in such prolonged experiments, and we ought not perhaps to expect them from purely practical men, who, in our country, are generally rent-paying farmers. But they must and will be made, as individuals and societies become impressed with clearer views of the precise position in which scientific agriculture now stands.

I may draw the attention of the reader to the illustration which this experiment of Mr Caird's affords of the varying produce of different portions of the same field, considered uniform in quality throughout. The three unlimed acres yielded of grain 44, 40, and 43 bushels respectively, being a difference of 4 bushels, or 10 per cent, between the first and second unlimed acres. We are unable to compare the differences in the produce of straw. On the almost universal occurrence of such natural differences I have elsewhere insisted, (p. 48.) Almost every new series of comparative results we examine enforces more the necessity of duplicate or triplicate trials, if we would obtain numerical results, on which reliance can be placed.

§ 6.—*Suggestions for experiments with silicate of lime, and with burned limes which contain it.*

I have shown in a preceding section that burned limes differ chiefly in the proportions of siliceous or earthy matter, of magnesia, and of phosphate of lime, which they severally contain. It is desirable, not merely for the purpose of testing theoretical views, but with a view to the economical benefit of those districts in which different kinds of lime are within the reach of the farmer, that precise experiments, with the view of testing the special effects of each, and their comparative values

for this or that crop or kind of land, should be generally undertaken.

As to the earthy and siliceous matter which, in some limestones daily used for agricultural purposes, forms a considerable percentage, I have stated that, during the burning, it combines with the lime and forms silicate of lime. It is not known, however, what purpose this silicate of lime serves in reference to vegetation.

Does it merely, in proportion to its quantity, lessen the ordinary effects which would be produced by an equal weight of pure lime? Is it a mere inert mixture?

Or does it, as some suppose, supply silica to the growing plant in a state in which it can be taken up, and does it thus in reality render the lime which contains it more valuable?

These are questions which can only be solved by comparative experiments.

1°. With *silicate of lime*. This compound is not manufactured for experimental purposes, but it exists abundantly in many districts as a refuse slag of the iron furnaces, and is much used in mending the roads. With this form of silicate of lime I would suggest that experiments should be made.

a In place of ordinary lime, chalk, or marl, on soils and crops of all kinds. Of course, whatever its action may be, it must not be expected to be so speedy as that of quicklime, or even of chalk.

In regard to corn crops, it should be specially observed if it has the effect of strengthening the straw, as the silica it contains might lead us to suppose. If it has, this slag would then acquire a definite value, because of its being applicable to a definite purpose.

b This possible effect of strengthening the straw recommends the trial of the slag on peaty soils, which are accustomed to produce a weak, yellow, and sickly straw. While, by its weight, the slag will consolidate such soils, the acid of the peaty matter will decompose the silicate of lime, and, while it becomes itself neutralised, will liberate silica in a form in which it may be useful to the plant.

For the purpose of being applied in this way, the slag ought

to be in the state of powder. It is easy to obtain it in this state by causing it to flow into water as it issues from the smelting furnace in which it is formed.

2°. *With burned limes which contain silicate of lime.* To perform these experiments, the relative proportions of combined silica in each of two limes should be ascertained, and comparative experiments made with the two under similar circumstances. Or those who are really desirous of lending a helping hand to this inquiry, may artificially mix a portion of siliceous sand with the limestone as it burns in the kiln, and thus cause the production of a portion of silicate of lime during the burning. With lime thus prepared, compared with pure lime, experiments can readily be made.*

It is a matter of very wide observation, that lime has the effect of strengthening the straw. Some say that lime and salt succeed better. But how this result is brought about—whether all varieties of non-magnesian lime act alike—whether the proportion of siliceous matter which a lime contains has any connexion with this result—whether the straw thus strengthened contains more silica—whether it is strengthened only by having the rapidity of its growth diminished;—these are questions in regard to which we have no experimental observations to guide us to a satisfactory answer.

* The limes and limestones, of which the analysis has been given in § 2, contain comparatively little siliceous matter. Many, however, which burn very well, and are in extensive use, contain much more. The following numbers represent the composition of two limestones from the upper Ludlow rocks, on the borders of Denbigh :—

	No. I.	No. II.
Carbonate of lime,	83.58	69.07
Sulphate of lime,	0.37	0.41
Phosphate of lime,	0.14	0.12
Carbonate of magnesia,	0.66	1.47
Alumina and oxide of iron,	2.67	5.24
Insoluble siliceous matter,	12.73	23.69
	100.15	100

The limes produced by the burning of these limestones must contain much silicate, and ought to be modified in their action, as compared with pure limes, accordingly. The composition of others, containing still more silica, will be found in *The Use of Lime in Agriculture*, p. 35.

It may nevertheless be, that natural differences in the lime do modify this peculiar virtue, and that the different results in regard to the straw, which are observed in some soils and districts, may be connected with these natural differences.

When shell-sand, the purest varieties of which always contain a certain proportion of siliceous sand, are burnt in a kiln, they yield a lime in which a considerable proportion of silicate is always present. This burnt shell-sand has lately been recommended very highly as an application to the land, and the value of the silicates it contains has been much extolled. Experiments which shall clearly make out the precise effect of the silicates in our different varieties of lime, are, therefore, much to be desired. They will prove both theoretically and economically useful.*

§ 7.—*Suggestions for experiments with magnesia, and with limes which contain it in considerable proportions.*

All limes, as I have said, contain magnesia, but those called dolomitic or magnesian often contain it in large proportion. In the magnesian limestones of the county of Durham, the carbonate of magnesia varies from 2 to 45 per cent of their whole weight.

In this district, the value of a lime for agricultural purposes is determined very much by the proportion of magnesia it contains. It is very desirable, therefore, to ascertain the precise nature of the effect produced by magnesia upon different soils and crops. Is this effect also produced equally by caustic or burned magnesia, and by carbonate of magnesia? Is the carbonate, as some have stated, harmless, or is it merely more slow in its action? On what property of magnesia does its injurious action depend? Does the extent or rapidity of its injurious action depend in any degree on the nature of the soil to which it is applied?

In my published *Lectures* I have thrown out the conjecture, that the tendency to retain the caustic form for a longer period than the lime with which it is mixed, may be a cause of the injurious action of magnesia. It has since occurred to me, from

* See my *Contributions to Scientific Agriculture*, pp. 59 and 125; and *Use of Lime in Agriculture*, p. 253.

finding sulphate of magnesia in the soil and waters of the county of Durham, that the large production of this salt in a soil to which a magnesian lime is added, may be another cause of its alleged burning effect upon crops. Iron pyrites, and other compounds of sulphur, exist abundantly in many soils. These are continually undergoing oxidation, and giving rise to the production of sulphuric acid, which, with lime, forms gypsum; and with magnesia, sulphate of magnesia.

It is the prevailing opinion in northern America, where gypsum is extensively used in agriculture, that an excess of this substance in the soil does no harm; but such is not likely to be the case with the very soluble sulphate of magnesia. Like other very soluble saline matters, when they abound in the soil, it will produce injurious effects if it be absorbed by growing plants in too large a quantity. Upon those soils, therefore, in which sulphur in any state of combination exists in larger quantity than is usual, magnesia may produce more speedy and more marked injurious effects than upon others. This is a point which is capable of being tested by experiment, and is deserving of investigation. I would suggest that experiments should be made.

1°. With caustic, or calcined magnesia, applied alone, in different proportions, to different crops, and at different seasons.

2°. With carbonate of magnesia, applied alone, in proportions and circumstances equally varied.

3°. With caustic magnesia, in comparison with carbonate of magnesia, applied in equivalent proportions. Are their effects different in kind or only in degree, as is the case with carbonate of lime in comparison with quicklime?

Carbonate of magnesia is not recommended here for the first time. In consequence of my previous recommendations, it has been tried in numerous experiments by Mr Gardiner, at Barochan in Renfrewshire,* and by Mr Main, at Whitehill in Mid-Lothian.† It was never applied alone by these gentlemen,

* *Transactions of the Highland Society*, March 1845, p. 411, *et seq.*, and July 1847, p. 20, *et seq.*

† *Ibid.* March 1849, p. 532, *et seq.*

however, but always as an ingredient of mixed manures, in which it formed only a small proportion. These experiments, therefore, throw no light upon the special effects of this substance on our different crops and soils. This field of inquiry is consequently still open.

4°. With limes containing magnesia in different proportions. The proportions in each case should be ascertained by analysis,* and they should be tried—

a In comparison with purer limes applied in equal quantities on the same soil, subjected to similar treatment, modes of cropping, &c., that the special effects of the magnesia on grass, root, and corn crops, may as far as possible be ascertained.

b If the effects of pure and magnesian lime be the same in *kind*, will a smaller quantity of the latter produce an effect equal in amount and equally durable?

c In what proportions can a lime which contains a given quantity of magnesia be safely applied to a soil of a given composition in a given climate?

d Is an efficient drainage of the soil any preventive of the injurious effects of magnesian limes?

This question is based upon the conjecture thrown out above, that the production of sulphate, or of some other very soluble salts of magnesia, may be one cause of the injurious action of this substance. In well-drained land, the rain that sinks through the soil in wet weather carries downwards, and not unfrequently out of the soil altogether, a portion of the saline matter it contains in excess. In undrained land, this saline matter remains and accumulates, and in dry weather rises towards the surface, and proves a source of injury to the crops that cover it. It appears, therefore, worthy of inquiry how far the effect of magnesian limes is modified by the introduction of what is called *thorough* drainage.

I may add, in reference to the experiments with pure *caustic*

* I think it likely that burned magnesian limes may not unfrequently contain, and yield to water, a sensible quantity of sulphate of magnesia. I have not hitherto ascertained this fact in my laboratory, but the subject is deserving of investigation in connexion with the analyses recommended in the text.

and carbonated magnesia, that though these substances are in this country sold at too high a price to admit of their being applied in the pure form by the farmer, however beneficial their action may prove to be on this or that crop, yet that in some parts of the world carbonate and hydrate* of magnesia occur so abundantly as native minerals, that they can be procured at a price which is almost nominal. A very pure white magnesian rock of this kind has lately been imported from Smyrna, and employed in the manufacture of Epsom salts. With such substances as this, and especially where it naturally occurs, the experiments I have recommended could be very easily performed.

* *Hydrate* means a combination of magnesia with water. Slaked lime is such a combination with water, and is called by chemists hydrate of lime.

CHAPTER XV.

Experiments with lime—*continued.* Experiments with phosphate of lime applied alone. Suggestions for comparative experiments with burned limes containing the phosphate of lime in different proportions. Connexion of the geology of a district with the probable success of experiments with lime in general, or with lime of different varieties. Suggestions for experiments on over-limed land. Experiments on the comparative economy of large and small doses of lime. Experiments on the use of lime in improving the quality of turnips, especially on fenny or peaty land. Suggestions for experiments with lime in the diseases called fingers-and-toes in turnips, and sedge or tulip-root in oats. Does lime always hasten the ripening of corn? Suggestions for miscellaneous experiments with lime.

§ 1.—*Experiments with native phosphate of lime applied alone.*

THE third important distinction among limes is, that they contain variable proportions of phosphate of lime. The economical value of this substance as it occurs in bones has been long recognised. But, in bones, it is associated with a considerable proportion of organic matter, which modifies and exalts its apparent action very much. Experiments, however, have been made with burned bones, from which the organic matter has been expelled by heat, and with decidedly beneficial effects. Thus Mr Lawes, in 1845, in his turnip crop, obtained the following results, per imperial acre :—

	Bulbs.		Tops.	
No manure gave .	0 tons	13½ cwt.	0 tons	14 cwt.
Farm-yard manure, 12 tons,	17 ...	1 ...	7 ...	7 ...
Calcined bone-dust, 400 lb.,	10 ...	4 ...	3 ...	12 ...
Do. and 134 lb. of sulphuric acid,	12 ...	18¼ ...	3 ...	17 ...
Do. and 268 lb. of sulphuric acid,	13 ...	11 ...	4 ...	14 ...

Thus the quantity of bulbs was largely increased by the bone earth, and more so when it was minutely divided by means of

sulphuric acid. The growth of tops, as we should expect, was not so much promoted by the calcined bones as by the farm-yard manure.

But experiments have also been made with native mineral phosphates, which, in some parts of the world, occur in sufficient abundance to admit of their being used for economical purposes. Thus—

1°. *With apatite*, a comparatively pure native phosphate of lime, Mr Lawes made an experiment in 1844, with the following effect on the weight of turnip bulbs, per imperial acre :—

No manure gave . . .	2 tons	4 cwt.	of bulbs.	
Farm-yard manure, 12 tons, .	10 ...	15 ...	...	
Apatite, ground, 3 cwt., . .	3 ...	1 ...	...	
Do., 200 lb., dissolved in about 1 cwt. of sulphuric acid,	6 ...	15 ...	...	
Do., 270 lb., with 104 lb. of acid,	7 ...	3 ...	...	*

Here, also, the mineral phosphate also produced a notable increase in the produce. Reduced to powder merely, it could not act either so efficiently or so quickly; but, when minutely divided by means of sulphuric acid, its sensible effects were largely augmented. Of course, it may be said that the sulphuric acid employed had a share in the effect produced, and no doubt it may have had, but we are not at present in a condition to say how much ought really to be ascribed to its influence.

2°. *With the fossil phosphates of the green sand.*—Of the occurrence of phosphate nodules and marls in the green sand and in the crag formations, I have already treated in the preceding chapter.† An experiment with these phosphatic nodules, (coprolites, as they were at first called,) dissolved by means of sulphuric acid, was made, in 1846, upon his turnip crop, (variety, white loaf,) in comparison with bones, by Mr Cooper, of Blythburgh Lodge, near Langford, with the following results, per imperial acre. The whole field had been manured with farm-yard manure on the clover stubble, preparatory to the wheat-crop of 1845 :—

* *Journal of the Royal Agricultural Society*, viii., p. 510.

† See also *Use of Lime in Agriculture*, p. 236.

No manure gave	5 tons	15½ cwt. of bulbs.	
Bone-dust, 184 lb., Sulphuric acid, 70 lb.,	gave 14 ...	14¼ ...	...
Phosphate nodules, 3 cwt., Sulphuric acid, 168 lb.,	... 14 ...	8½ ...	...

Thus the 3 cwt. of the impure mineral phosphate gave sensibly the same weight of bulbs as the four bushels or 184 lb. of bones. It was remarked, however, that the boned turnips came away quicker, and for three months maintained a more rapid growth than the others. Two things are not stated by Mr Cooper, which it would have been desirable to know; *first*, the proportion of phosphate of lime which the nodules employed by him contained; and, *second*, the relative weights of tops produced by the several patches.

It is satisfactory, however, to be able to conclude that these mineral phosphates, when prepared by means of sulphuric acid, are really powerfully fertilising substances, and to learn from Mr Cooper that the nodules he employed were purchased at the low price of three shillings a hundredweight. These facts ought not only to stimulate our search for further deposits of such nodules, but to urge practical men to more numerous and more precise experiments with them when found.

§ 2.—*Suggestions for comparative experiments with burned limes containing the phosphate of lime in different proportions.*

If limestones or burned limes contain the phosphate in different proportions, they ought to produce sensibly different effects upon the land. They ought also, in consequence, to be more or less valuable to the practical farmer.

The analyses of limestones introduced into the preceding chapter show that they do thus differ. Though probably always present, yet, in some cases, the proportion of phosphate is exceedingly small. Thus, two specimens of magnesian limestone from the county of Durham gave me only 0.07 and 0.015 per cent respectively, while the mountain limestone from Carluke, of which I have already spoken, (p. 226,) contained 1.39 per cent, and, in the burned state, 2.33 per cent.

To some persons these quantities may both appear too small to produce any very sensible effect upon the land or the crops. In answer to this, I have already shown that a ton of lime containing 2 per cent of phosphate carries on to the land 45 lb. of this compound, and, therefore, that a large dose of lime must mix with the soil a quantity of phosphate, which cannot be without an important influence.

But it may also be said that, in the experiments with mineral phosphates in a comparatively pure state, the results of which have been given in the preceding section, their effects were small when applied in the state of powder, and that they became distinctly marked only when the phosphates were dissolved in sulphuric acid. It is an advantage, however, which we gain by the burning and slaking of lime that it is thereby reduced to the state of an exceedingly fine powder, and that any substance which is mixed with the lime is at the same time brought into an exceedingly minute state of division. In regard to the phosphate of lime which burned limes contain, we may therefore consider that the slaking does for it in a great measure what the action of the acid does for the compact mineral apatite and phosphatic nodules, and that in our common limes it is in a sufficiently divided state to act at once upon the land, and to produce an effect in proportion to the quantity of it which has been applied. I would therefore suggest that experiments should be made,—

a With the different limes which are accessible in a district, in which by analysis a sensible difference in the proportion of phosphates has been found.

b On different soils, and on such as have been previously subjected to different kinds of manuring.

It is especially desirable to ascertain how far the previous use of bones affects the comparative action of each variety of lime; how far the previous application of each variety modifies the effect of bones subsequently applied to the land; if they appear to exhaust the land in different degrees, or in different periods of time; if one variety, for example, can be safely applied for a much longer period than another; if they differently affect the growth of corn crops, and especially the filling

of the ear; if they influence in different ways the quality of the turnip crop, or of grass for feeding, and so on.

Observations of this kind, suggested by what we know of the composition of different varieties of lime, will not only test our theoretical views, and give us clearer ideas as to the special effects of the substances which different limestones contain upon our different crops, but will also lead practical men in each district to the employment of that variety of lime which, under all the circumstances, is likely to yield them the largest return of pecuniary profit.

§ 3.—*Connexion of the geology of a district with the probable success of experiments with lime in general, or with lime of different varieties.*

There are certain geological considerations which the experimenter upon the use of lime may usefully bear in mind, both in reference to the localities in which the application of lime generally is recommended, and to those in which limes rich in magnesia or other substances may be tried with comparative safety, and with the hope of advantage. Thus—

1°. Where the average proportion of lime in the rocks of the country is small, it may be assumed as almost certain in our climate that the application of lime is likely to be followed by profitable improvement. On the other hand, where the rocks are rich in lime there is a presumption that the soils, or the springs that water it, will also contain it in considerable quantity. In regard to this point, however, no safe conclusion can be drawn from purely geological considerations. There are so many circumstances which conspire to remove lime from the soil, that a chemical analysis, or a careful testing with acid, can alone be depended upon in proof of its containing a sufficient natural supply of this necessary ingredient.

2°. In districts which abound naturally in magnesia, the use of purer limes—such as the chalks and mountain limestones—is indicated. Where the rocks are poor in magnesia, though the strongly magnesian limes may not be proper for ordinary and general use, yet an admixture of them with other limes, or an

occasional application of such a lime by itself, will be likely to promote in a greater degree the productiveness of the soil.

3°. In like manner, should it be proved by experiments, such as have been suggested in the previous sections, that limes which contain a proportion of silicate are specially useful for certain soils and crops, it will then become a matter for consideration, in localities where the most accessible limes are of a very pure character, whether an importation of less pure lime may not occasionally be profitable, or whether, during the process of burning in the kiln, siliceous sand may not be advantageously added to it.

The natural presence of gypsum in a soil, or of phosphate of lime in considerable quantity, will also materially interfere with the results of many of those experiments I have recommended; their possible influence, therefore, ought in all cases to be taken carefully into account.

§ 4.—*Suggestions for experiments on over-limed land.*

Land to which lime has been applied too frequently, or in too large doses, is not only liable to exhaustion, but to be rendered so light, open, and spungy, as to sink under the foot—if of a fenny or peaty character, to become powdery and liable to be drifted by the wind—and though it may still grow turnips and barley, to be unfit to yield profitable crops of sown grasses and oats.

The term *overlimed* is given to such land,—a designation which seems to imply that in the soil lime really exists in too great abundance. Analysis, however, has satisfied me that such is not the case, and that the evil is a mechanical or physical, and not a chemical one.*

When this evil presents itself, therefore, I would suggest, along with bountiful treatment—to restore it if exhausted by previous cropping—the trial of one or more of the following methods of solidifying it:—

1°. Laying down to grass, and keeping some years in pasture.

2°. Eating off turnips with sheep.

* See *Contributions to Scientific Agriculture*, p. 24; or *Use of Lime in Agriculture*, p. 121.

3°. Ploughing shallow and as seldom as possible, or paring with the breast plough, by which the under soil remains undisturbed.

4°. Use of the clod-crusher or the peg-roller to press it down; treading with horses, or even with men, who, in some parts of England, tread it down for one shilling and sixpence an acre.

By the use of such means as these, by employing drilled manures, and by carefully avoiding any stirring of the surface which can be avoided, the evils of over-liming may be overcome.

Of course, the reader will understand that the employment of methods which, like the above, are available everywhere, does not exclude the admirable method of claying, by which the fen farmers know so well how to cure the kind of evil I have been speaking of. Anything which, in the form of clay or compost, can be laid on the surface to add to its solidity, will produce the mechanical effect which is desired; but such applications are not within the easy reach of the farmer in all the localities where the evil is observed.

§ 5.—*Experiments on the comparative economy of large and small doses of lime.*

In the application of lime to land even of the same kind, and intended to be cropped in a similar way, a diversity of practice prevails in different districts and countries. Some apply large doses at long intervals, others smaller doses more frequently repeated. Local circumstances—such as the tenure of land, and the distance from which lime has to be brought—very frequently determine local practice in this respect. But where circumstances admit of either practice, it is a matter of some moment to inquire which of the two is the more economical. In my other published works, I have discussed this question;* and having shown,

1°. That a certain percentage of lime is, in our climate, necessary to the maximum fertility of the land;

2°. That, to keep up this necessary percentage, supposing it already to exist, practical experience has shown, that an addition at the rate of about ten bushels a-year is required by each imperial acre;

* *Lectures*, 2d edition, p. 679; and *Use of Lime in Agriculture*, p. 94, *et seq.*

3°. That the full action of lime upon the crops does not take place for two or three years after its application;

I have endeavoured to show that, when one large dose of lime has been laid upon land which had been long unlimed, it is a more profitable, as well as a more natural method, to apply it afterwards in successive small doses at comparatively short intervals.

This conclusion is deserving of being tested by experimental trials. These will, of course, require a lengthened time for their completion, and can only be undertaken by persons whose tenure of the land they hold is of considerable duration. They ought to be made on land limed for the first time, or to which no lime has been applied during the last fifteen or twenty years, and should be conducted as follows:—

1°. Over the whole experimental piece of land, the large dose of two or three hundred bushels of lime an acre should be spread alike.

2°. The land should then be divided into six portions of not less than one or two acres in extent, and to each of these portions further applications of lime should be made in different proportions at different intervals. Thus—

a To one portion a fifth of the first application—40 to 60 bushels—every four years.

b To another portion, a third of the first application every six years.

c To another, two-fifths every eight years.

d To another, two-thirds at the end of twelve years.

e To another, four-fifths at the end of sixteen years.

The following scheme represents the field so divided:—

160 to 200 at 16 years.	40 or 50 every 4 years.	70 to 90 every 6 years.	Dressed once only.	80 to 100 every 8 years.	140 to 180 at 12 years.

This series of experiments is only single, and though, when arranged as above, the several trials could scarcely fail to afford interesting results, yet, if made in duplicate, as I have so fre-

quently recommended in regard to other experiments, their indications would be much more valuable. By having the relative positions of the several plots entered in an experiment book, the requisite attention can be easily given to each, though twelve in number, without perplexity.

The experimenter will, of course, follow the same system of culture, of manuring, and of cropping, on the whole field, during all the years of trial. The things to be especially observed are—

1°. The general physical state and condition of the land, in reference to all the operations of the farm.

2°. The relative weights, feeding properties, and money values of the successive corn and green crops which may be grown upon each experimental division.

A balance of the profit and loss on each portion, during the course of the twenty years' trial, would prove very valuable, theoretically, and very useful, economically. It will not be necessary to wait for the lapse of this long period before any of the results are published. The state and produce of the several plots may be made known in each successive year, after the first large dose has been added. These will be found to be not only interesting, but useful also, for many purposes.

§ 6.—*Experiments on the use of lime in improving the quality of turnips, especially on fenny or peaty land.*

It is a matter of surprise to practical men, that turnips and other root-crops, even of the same variety, and when raised from the same seed, often differ remarkably in feeding value. In the Lothians, cattle can be fattened on turnips alone; in Dumfries-shire this is generally pronounced to be either difficult or impossible. On the fenny land of Lincolnshire, and the adjoining counties, a similar defect in the quality of the turnip crop is complained of; while on the sharp forest land which skirts it towards the west, the feeding quality of this root is pronounced to be excellent.

The nature of the chemical differences which must exist between the two qualities of turnips, can, at present, only be guessed at. They may abound, more or less, in those compounds of nitrogen, of which I have spoken in the preceding

chapter, and upon which their feeding property, in a considerable degree, depends. Or they may differ in the proportions of saline and other mineral matter they contain, or in the relative proportions of sugar, &c. which may exist in them at the same periods of their growth. In regard to these points, and in the absence of accurate analyses, we can only offer conjectures.

But how the defect in quality is to be remedied, is a more important question to the practical man. As a means of improving the quality, I think lime is deserving of a fair and extensive trial. I do not enter here into the discussion of the reasons which have led me to this opinion; but as there are no experienced practical men who will deny that, as a general rule, lime is useful to peaty or fenny soils, I venture to recommend—

1°. That on such soils, the practice of heavy and successive liming should be resorted to, among other purposes, with the view of testing the value of lime in improving the nutritive quality of root-crops, and especially of turnips.

2°. That on soils of other kinds on which these root-crops are found by experience to be deficient in fattening quality, the application of lime, in considerable doses, should also be tried.

3°. It may happen that, in some parts of the country, the practical man may say, that his land has already been limed, without any good result of the kind in question having followed. In such a case, I would recommend a series of comparative trials to be made in duplicate with lime, bones, sulphate of ammonia, and rape-cake, upon land to which the ordinary application of farm-yard manure has been made. The following scheme represents the kind of arrangement which may be adopted:—

Lime and rape-cake.	Lime and dung.	Lime and bones.	Lime and sulphate of ammonia.	Lime and rape-cake.	Lime and bones.	Lime and sulphate of ammonia.	Lime and dung.
Dung alone.	Dung and bones.	Dung and sulphate of ammonia.	Dung and rape-cake.	Dung alone.	Dung and bones.	Dung and sulphate of ammonia.	Dung and rape-cake.

The quantities of the several substances which ought to be applied may be left very much to the discretion of the experimenter. The dose of lime ought not to be small, and the application of bones should not be less than twenty bushels an acre if they are used in the state of dust. If they are dissolved by means of acid, half this quantity may be tried. The whole of the upper half of the field should be limed in the preceding autumn, or in the early spring; the farm-yard manure should be applied at the usual time when preparing the land for the turnip crop; and the bones and other substances should be afterwards drilled in with the seed.

The things to be observed are,—

1°. The effects of each application on the general appearance and quantity of the crop.

2°. Their effects on the quality as indicated—

a By the appearance, taste, and other sensible qualities of the turnips raised, from which practical men can in many cases draw very trustworthy conclusions.

b By their effects in an actual trial made with them in the feeding of stock.

c By the results of a carefully executed chemical analysis, when such can be obtained.

The result of such an inquiry to the practical farmer will be, that he will obtain information whether the quality of his turnips is likely to be improved by the use of lime alone without any other change of his ordinary practice; whether he must apply bones, or rape-cake, or salts of ammonia; and whether these will give him most profit when they are used with or without the previous addition of lime.

§ 7.—*Suggestions for experiments with lime in the diseases called fingers-and-toes in turnips, and sedge or tulip-root in oats.*

These two diseases are well known to practical men; the former, I believe, on all varieties of turnips on certain soils, the latter chiefly in a variety of oat known in Scotland as the Hopeton oat.—(P. 14.)

I have elsewhere discussed at some length the subject of fingers-and-toes in turnips,* and will only quote here, therefore, as the result to which that discussion has led me. "That the cure for this disease appears to be the application of a large dose of lime to the stubble-land in the autumn, after it has been turned up by the plough."† The questions to be asked by the way of experiment therefore are—

1°. Will a large dose of 100 to 200 bushels of lime, applied in that way, prevent this disease of fingers-and-toes from appearing in the subsequent turnip crop?

2°. Will the application of an equal quantity of lime to another portion of the same land, if laid on in spring, fail to prevent the disease? The experience of Mr Wilson of Cumledge answers this in the affirmative, but it is desirable to test it by a wider experience.

3°. Are all soils poor in lime upon which this disease appears? My own experience is in the affirmative, but more numerous analyses may bring to light exceptions to this result, and may lead us to a more general cause of the evil.

As to the disease in oats called sedge or tulip-root, I have never myself had an opportunity of practically investigating its cause or character. On the supposition, however, that, like that of fingers-and-toes, it may be caused or accompanied by the appearance of insects in the roots, I venture to inquire whether it is known—

1°. If lime has any effect in preventing its recurrence? and

2°. If it has ever been ascertained whether those soils in which it appears are poor or rich in lime?

If they are generally poor in lime, the trial of lime as a preventive of the disease is indicated. If no trials with lime have been made by any of my readers, it may be interesting to make experiments with this substance, especially in Scotland, where the oat-crop is superior in quality as well as in value to the country at large.

* See *Use of Lime in Agriculture*, p. 195. The facts there stated will, I think, interest the reader.

† Ibid. p. 201.

§ 8.—*Does lime always hasten the ripening of corn?*

In my little work on the *Use of Lime*, I have stated, "that it is true of all our cultivated crops, but especially of crops of corn, that their full growth is attained more speedily when the land is limed, and that they are ready for the harvest from ten to fourteen days earlier." But in a note, I have added, as the results of information given me by farmers in the counties referred to, "that in East Northumberland the liming of the land does not hasten the ripening of the crop. It makes the land more productive, and the crop larger, though not ready to cut at so early a period. This is explained on the spot, by saying that the growth of straw and ear being greater than before, the ripening is retarded by this cause. In Caithness, bog-marl is said to make the oats later, while quicklime makes them earlier."*

These extracts suggest the questions—

1°. Are there really any exceptions to the general rule, that lime applied alone, without any other change in the ordinary treatment of the land, hastens the ripening of the crop?

2°. Where crops are apt to be overtaken by an early winter, will a more copious use of lime enable them to ripen and to be reaped before the winter arrives?

3°. If there be exceptions to the general rule, under what circumstances do they occur? What is the peculiarity of the soil, of its condition, treatment, exposure, &c.,; and what sensible difference, if any, is seen in those crops, the ripening of which is not hastened by the use of lime?

The experiments to be undertaken with the view of obtaining answers to these questions are sufficiently obvious.

§ 9.—*Suggestions for miscellaneous experiments with lime.*

There are many miscellaneous inquiries in respect to the use of lime which may be made the subject of experiment, such as—

1°. The season of the year, and the period of the rotation at

* *Use of Lime in Agriculture*, p. 111.

which on different soils, under different modes of cropping, and in different climates, it is most profitably applied.

2°. The comparative effects, immediate and ultimate, of the same quantities of lime applied in the quick and the compost states to different soils, and in reference to particular crops.

3°. Lucerne, for example, is a lime-loving plant, and is said to be benefited by repeated limings. Will an annual small dusting of lime over the young shoots in spring, or larger doses dug in between the drills at longer intervals, or a heavy liming once for all, when the crop is sown, be the most profitable? Or will an occasional application of lime-compost be more favourable to this crop? Such questions as these, if asked by the way of experiment, would lead to economical practical results, and would throw light at the same time on the physiological relations of the plant.

4°. In the grass lands of upper Dumfriesshire, and of the higher parts of Yorkshire, lime is said to be more durable in its effects when laid on in a wet or half-mortary (locally *dracket* or *dabby*) state, than when applied in the dry powdery form to which it falls by ordinary slaking. This statement is worthy of being tested by experiment. If more lasting in its effects when applied in this wet state, are its immediate effects not less?

5°. Lime and marl extirpate sorrel, and they in many localities cause moss to disappear from old pastures. But moisture in the air and in the soil cause moss to reappear in lawns, and parks, and pleasure-grounds, and upon old grass lands, which it is inconvenient or unsightly to plough up. Will an annual small top-dressing of quicklime, applied in early spring, not keep down this moss more effectually than large doses at distant intervals? Will a mixture of this lime with common salt be more efficacious if yearly repeated? Will the addition of dissolved bones, in small proportion to the lime, render ploughing up unnecessary? Will the use of one variety of lime produce the desired effect more readily or more completely than another? What are the comparative effects of magnesian and pure limes in this case, of such as contain more or less of the natural phosphate of lime, &c.?

I might mention many other interesting facts, or statements,

upon the examination of which time and labour in making field experiments might be usefully expended. It is sufficient for me, however, to repeat what I have elsewhere stated, that there is scarcely a single practical operation among the many with which the farmer is daily occupied, or a single opinion by which the field-culture of his land is influenced—the economical value of which may not be tested by rigorous experiment, and in regard to which field trials carefully conducted and regulated by weight and measure, would not supply valuable additions to our existing stock of certain knowledge.

CHAPTER XVI.

Experiments with the compounds of baryta and alumina, and with burned clay and shale. Experiments with sulphate of baryta, sulphuret of barium, and carbonate of baryta. Suggestions for experiments with sulphate of alumina, and with common alum. Experiments with burned clay. What are the qualities which fit a clay for burning? Mechanical and chemical effects of burning upon a clay. How it afterwards acts when laid upon the soil. Suggestions for comparative experiments with burned clay. Experiments with bituminous and other shales burned and unburned.

§ 1.—*Experiments with sulphate of baryta, with sulphuret of barium, and with carbonate of baryta.*

1°. The *sulphate.* When treating of the uses of gypsum, I mentioned sulphate of baryta as having been tried to a small extent in comparison with it, and with a view to theoretical inquiry I recommended that farther comparative experiments should be made with this substance, (see p. 128.) In some localities this sulphate occurs in veins of considerable thickness, and may be procured at a comparatively cheap rate.

2°. The *sulphuret.* When the sulphate of baryta is mixed with charcoal, and heated to redness in a close crucible, it is deprived of its oxygen, and is converted into sulphuret of barium. This compound dissolves readily in water, and gives a solution possessed of a yellow colour and a sulphureous taste and smell. In regard to this substance, I find it stated that Mr Chapman of Pennsylvania tried it as a manure, and found it to "exceed gypsum in its effects, not only on dry gravelly lands, but also on clays. It expelled insects from his garden, and he considered it the most powerful manure ever yet discovered."* I have not formally recommended any trials to be made with sulphurets in the previous chapters of this work. In the case of substances like this sulphuret of barium, however,

* Nicholson's *American Farmer's Assistant,* 1820, p. 221.

of which only the sulphur, so far as we know, can be of any use to the plant, trials on different crops and soils may be made with the prospect of obtaining from them useful information. They will not only test the statements of Mr Chapman, but may throw light upon the economical value of such applications, and upon the way in which sulphur acts in directly influencing the growth of plants.

3°. The *carbonate* of baryta occurs in some of our mining districts in considerable quantity, and is sold at the rate of a few pounds a ton. It possesses general properties which resemble those of carbonate of lime. But baryta is not found in plants, and cannot, therefore, like lime, directly benefit them by yielding what is necessary to form their substance. It would, therefore, be interesting to ascertain by actual trials, on a small scale, what influence an application of carbonate of baryta would have upon the fertility of the soil in comparison with carbonate of lime. Whatever effect it might have for good would most probably be due to an action exercised on the constituents of the soil alone, while, if vegetation were injured by it, the injury might arise from the baryta being actually absorbed by the roots, and acting as a poison on the plant.*

§ 2.—*Suggestions for experiments with sulphate of alumina, and with common alum.*

Alumina, like baryta, is not as yet recognised to be a necessary ingredient in our cultivated plants. It occurs in the club-moss (*lycopodium*) and probably in some other plants in sensible quantity, but in those which are grown for the food of man and of our domestic animals it has not hitherto been proved to be necessarily present. This absence of alumina from the plant cannot arise from its scarcity in the soil—since of nearly all soils it forms a very considerable proportion. It is rather to be regarded as an arrangement of nature, by which alumina is caused to give tenacity to soils, and a firmer hold to the roots, while the latter are so organised as not to absorb the alumina in any sensible quantity.

* As to the possibility of such absorption, see the author's *Lectures on Agricultural Chemistry and Geology*, second edition, p. 125.

If a salt of alumina be applied to the soil, therefore, we are justified in anticipating that it would not be directly taken up by the roots, however soluble it may be, and that whatever influence it might exercise upon vegetation should be ascribed mainly to the acid or other substances with which the alumina is combined. It is desirable, therefore, to make experiments with one or other, or with both of two compounds of alumina, now to be met with readily in the market. These are the sulphate of alumina and common alum.

1° *Sulphate of Alumina* is a colourless deliquescent salt which has a strongly astringent taste, and consists of

Sulphuric acid, . .	36.0
Alumina, . . .	15.4
Water, ...	48.6
	100

The effects of this substance should be tried in comparison with those of gypsum and of sulphuric acid—the same quantity of acid in each of these forms being applied to the same extent of land. The comparative experiment with sulphuric acid will be especially instructive.

2° *Common alum* consists of

Potash, . .	9.9	or of		
Alumina, .	10.8		Sulphate of alumina (dry,)	36.1
Sulphuric acid,	33.8		Sulphate of potash, .	18.4
Water, . .	45.5		Water, . . .	45.5
	100			100

I am not aware of any field experiments having been made with alum, but there is little doubt that it would be found to exhibit a specific action upon some soils and crops.

In the case of alum, however, the presence of sulphate of potash in it will prevent us from ascribing the whole of any effect which may be produced by it to its sulphuric acid alone. The alum must, therefore, be tried in comparison with sulphate of potash, and with gypsum applied at the same time, and in similar circumstances. If 18½ lb. of sulphate of potash do not produce an equal effect with 100·lb. of alum, then the acid of the sul-

phate of alumina present in the latter, or the state in which this acid exists in the salt, has an appreciable influence. If 18½ lb. of unburned gypsum act differently from the same weight of sulphate of potash, (p. 128,) then the presence of the lime and the potash, respectively, may be regarded as modifying the apparent effects of each. And if 74 lb. of unburned gypsum, which contain as much sulphuric acid as 100 lb. of alum, affect the crop or land differently from this weight of alum, then it is not to the quantity of acid alone that the influence of the alum is to be ascribed, but in part, also, to the state of combination in which it exists, or to the substances with which it is combined. In regard to these salts of alumina, it should be particularly observed—

1°. What effect they produce on the appearance, the quantity, or the quality of our different crops.

2°. Have they any special influence, as other sulphates are supposed to have, on leguminous crops? Do they more distinctly act upon cabbage, onions, &c., than upon other cultivated plants?

3°. Do they especially extirpate certain kinds of natural plants or weeds, and bring up others?

§ 3. *Experiments with burned clay—what are the qualities which fit a clay for burning.*

Burned clay has by many been recommended as a useful application to the land; and in numerous instances it has been a source of profit to those who have employed it.* Mr Woodward states that it renders the soil more friable, so that it can be worked with less labour, and especially aids the culture of green crops. On a crop of wheat grown upon drained Oxford clay, Mr Pusey states that, in 1845, it added eight bushels to the produce of grain yielded by one of his fields.

No manure gave . .	37¾	bushels per acre.
80 yards burned clay (cost 45s.),	45½	" "
80 do., and sheep folded, .	47½	" "

* See especially General Beatson's *New System of Cultivation*, second edition; 1821. Also papers in the *Royal Agricultural Journal* by Mr Pym, iii. p. 323; Mr Randell, v. p. 113; Mr Pusey, vi. p. 477; Mr Mechi, vii. p. 297; Mr Poppy, vii. p. 142; and Mr Long, vii. p. 245.

This clay possessed the quality so often seen in the Oxford clay, of being like bird-lime in wet weather, and in dry summers like a stone, requiring a pick-axe to break it.

But there are three things, in regard to burned clay, which are far from being cleared up.

1°. Are all clays equally efficacious, when burned in a similar way?

2°. If not equally efficacious, in what respect do the good differ from the bad clays, and by what qualities or characters are they to be distinguished?

3°. How do they act in improving the soil or the crops?

I shall briefly consider each of these questions.

1°. *Are all clays equally efficacious when burned in a similar way.* I believe the correct answer to this question is, that they are not. It is true that similar clays, in the same neighbourhood, often produce very different effects, according as they are well or ill burned; but experience appears to indicate that, with the most skilful treatment, there are many clays which cannot be profitably burned by the practical man.

The practice of paring and burning the surface, or of burning, in various ways, the scourings of ditches and refuse vegetable matter of different kinds, is not to be confounded with that of true clay-burning. Both practices, however, have these things in common—that the heaps or kilns must contain, or must be supplied with, a sufficient quantity of vegetable matter to enable them to burn thoroughly—that the burning should be slowly conducted, and with little access of air, a method which is well described by the epithet of *stifle*-burning—and that the heat should not be permitted to become so great as to produce what is called *over-burning.* But in regard to true stiff clays—

2°. *In what respects, physical or chemical, do the good differ from the bad*—those which are improved by burning from those which are not. These points have not as yet been sufficiently investigated or described. In general, I believe that such as burn most profitably are very impervious to water and air, are exceedingly tenacious, and harden very much under the influ-

ence of the sun. I am myself, however, unfamiliar with the physical characters of these clays on the large scale, though very many samples have been sent to me from a distance, and have been examined in my laboratory. As to their chemical composition, it has not been made out by analysis in what respect the good clays differ from the bad. This arises from the circumstance, that it is difficult to obtain specimens which can be ascertained, from practical men, to belong to each of the classes, in order that a comparative examination, of such as exhibit opposite effects in practice, might be simultaneously made.

Clays may differ not only in the proportions of alumina, silica, lime, and alkaline and organic matters, which they respectively contain, but also as regards the state of chemical combination in which these substances exist in the clay. When my attention was first drawn to this subject, I was inclined to look upon the proportion of lime in a clay as likely to exercise an important influence upon its comparative value for the purpose of burning. On this supposition the Oxford clay, in which I have found from 15 to 30 per cent of carbonate of lime, ought to possess very superior advantages for burning. I am not certain, however, that such is really the case, as clays have been sent to me, which were described to be well adapted for this process of improvement, and to be extensively employed for the purpose, in which the proportion of lime did not exceed 2 or 3 per cent. It is probable, however, that the relative proportions of the several constituents of a clay do affect not only the absolute value of a clay for burning, but also the method by which it may best be burned, and the way in which it acts when it is afterwards laid upon the land.

The state of chemical combination in which its several constituents exist in a clay has, however, quite as much to do with the good effect of burning upon them, and with their more useful action when afterwards spread upon the land. A diversity in this respect may possibly also be a cause of difference in the fitness of clays for the burning process, though, in reference to this point, chemical inquiries have not as yet been made.

I shall state my views of the effects of burning upon clays in a separate section.

§ 4.—*Mechanical and chemical effects of burning upon a clay. How it afterwards acts when applied to the soil.*

In considering the effects of burning upon clay, it is of importance to bear in mind that the action of the heat must neither be too great nor too prolonged, otherwise the clay will be overburned, and rendered comparatively useless for agricultural purposes. This fact is of especial importance in reference to the chemical changes which the clay undergoes, and the chemical action it afterwards exercises in the soil.

1°. The *mechanical effects* of such burning are simple and easy to be understood. The clay is hardened to a certain degree, without being made compact or melted. It has become porous, and, though it falls under the action of the weather, it does not again become adhesive, or tenacious and plastic. It thus tends to open and render lighter stiff clay soils to which it may be applied. It is chiefly to this mechanical action that the greater friability of heavy land, after being dressed with burned clay, is to be ascribed, and the smaller amount of labour which is afterwards required to work it.

The beneficial action of burned clay has been ascribed altogether to its porosity. This enables the burned lumps, it is said, to absorb the ammonia of the atmosphere, and thus to bring within the reach of plants from a natural source what they might otherwise be unable to obtain in sufficient abundance. It is certain that all porous bodies do absorb gases and vapours in comparatively large proportion, and, by condensing all the constituents of the atmosphere in their pores, the pieces of burned clay may really be useful to the growth of plants. It is a fancy, however, to suppose that the clay exercises this absorptive power, especially upon the ammonia, which exists, it is true, but in an almost infinitesimal quantity in the air. It may take in traces of ammonia along with the oxygen and nitrogen of the atmosphere, but these alone cannot justly be regarded as likely to influence in a sensible degree the fertility of the soil to which

it is applied. Besides, as soon and as often as the pores are filled with water, they will cease to absorb gaseous matter, and thus their useful function ought then to cease.

It may be, however, that the porous quality of the clay may also facilitate evaporation from the surface of the soil, and may thus aid in keeping it dry. It will dry sooner in the air during the day than the tenacious unburned soil; and again absorbing moisture from the latter, it may both hasten the drying of the whole, and prevent its baking so hard together as it usually does.

These mechanical influences of burned clay are by no means to be undervalued, but its fertilising effects are in a very much greater degree to be ascribed to the chemical changes which the constituents of the clay undergo during the process of burning.

2°. *These chemical changes* are of such a kind as to render the constituents of the clay more soluble,—that is, soluble to a greater extent than before the burning,—both in water and in acids.

In experiments made upon this subject, the details of which I need not insert here, I have found that, after burning, pure water will often dissolve twice as much from the clay as it would before burning, and with much more ease. Acids, also, such as a mixture of nitric and muriatic acids, will leave from 5 to 8 per cent less of insoluble matter after they have been burned than when they are digested in the same acids for the same time in their natural state. This greater solubility must render them much more capable of yielding to the roots of plants the several mineral substances contained in them, and which plants can only derive from the soil.

That this is the true general explanation of the benefits of burning, is proved, I think, by the concurrent testimony—

a Of experience—that, by over-burning, clays lose their fertilising virtues;—and,

b Of chemical analysis—that, by such over-burning, new changes among the constituents of the clay take place, by which they are again rendered less soluble than when moderately burned.

It is quite clear, that if such be the true nature of the useful

action of burning upon clays, the chemical composition of a clay must, in a great measure, determine how far by burning it is likely to become useful as an improver of the soil, and ought to indicate when and where experiments should or may profitably be made with it.

3°. *How burned clay acts* when applied to the soil, becomes, after this explanation, very plain. By my experiments, a clay which, in its natural state, as taken from the field, yielded with difficulty three-quarters of a per cent (0.77) of soluble salts, of which one-third (0.24) was organic or combustible matter, gave readily to water, after being burned, one and three-fourths of a per cent (1.77) of soluble salts, of which only one-thirtieth part (0.06) was combustible matter.

Thus, while one ton of the natural clay yielded with difficulty 11 pounds of mineral matter, the burned yielded readily 36 pounds. The natural clay was also liable to become hard, baked together, and impervious to water, air, or roots, while the burned is always open, pervious to rains, and accessible to the roots.

This soluble matter consists of potash, soda, lime, magnesia, chlorine, sulphuric acid, silica,—nearly all the mineral ingredients, in short, which are necessary to the growth of plants,—in proportions which, of course, vary with each specimen of clay examined.

An idea will be formed of the importance of this greater solubility, and of the striking effects which it ought in some cases to produce, if it be recollected—

a That fifty or a hundred cart-loads or tons is not an unusual application of burned clay to an acre of land.

b That a hundred tons of some clays will yield not less than one and three-fourth tons, or 3900 pounds, of soluble mineral matter.

c That the natural clays often contain, or, for the purpose of burning them, are mixed with much vegetable matter, the ashes of which will increase still further the quantity of soluble mineral matter which they will be able to yield when burned. And lastly,

d That the whole mineral matter carried off by the grain,

straw, roots, and tops of an entire rotation of four years, on well-farmed land, is only about 1300 pounds.* In other words, a dressing of a hundred cart-loads an acre of burned clay, of good quality, is capable of yielding to water as much mineral matter as is required by twelve successive corn and root crops, supposing all that these crops contain to be permanently removed from the land.

Burning, therefore, like liming, owes its principal virtue to its power of rendering immediately available to the growth of plants the natural riches often so abundantly contained in the soil.

I do not insist, because it is unnecessary to the conviction of my readers, on the further fact, that while so much more of the mineral matter of the clay is rendered soluble in water by the burning, a very much greater increase takes place in the matters which are soluble in acid. A clay which, before burning, left 81 per cent of insoluble matter, after three hours' digestion with a mixture of strong nitric and muriatic acids, aided by heat, left 73 per cent only when burned and afterwards treated with acid in a similar way. The additional proportion thus rendered soluble in acids consists chiefly of alumina, but partly also of lime, magnesia, and alkaline matter. And as the carbonic and other acids produced in the soil do more slowly there for the benefit of plants, what our strong acids do for us more quickly in our laboratories, there is reason to believe that, besides the soluble matter which water can extract from burned clays, they are capable of yielding to plants a much larger quantity still in a more gradual way. The apparent practical benefits of burning clays, as a source of mineral food to plants, when viewed in this aspect, become very much exalted.

§ 5.—*Suggestions for comparative experiments with burned clay.*

It will appear to the readers of the preceding section, that the burning of clay is a process of amelioration which is really deserving of extensive trial. But clays vary in com-

* Johnston's *Lectures on Agricultural Chemistry and Geology*, 2d edition, p. 409.

position; and their value, when burned, will no doubt depend much upon this composition. Some abound in lime, some are richer in alkaline matter, some in magnesia, and some in alumina; and, as I have shown, they vary also in the state of chemical combination in which the constituents exist in them. It may be asked by experiment, however,

1°. Are clays which, like the Oxford clay, abound in lime, always beneficial, or are they good clays for burning? If so, it might be easy to mix lime or chalk, during the burning, with clays which, like those of the lias and the coal measures, are generally poor in lime.

2°. Are all the clays of the same geological formation usually good or bad for burning?

3°. Will the admixture of a little salt to a clay, to one rich in lime or otherwise, during the slow burning, render it more valuable?

4°. Do good clays always yield a sensibly larger quantity of soluble matter than bad clays after they have been burned in a similar manner? Can we establish the proportions of saline matter thus dissolved as a simple test of the relative values of different clays?

5°. Do they especially improve root and other green crops, as Mr Woodward states? These require much saline matter; and that they should be benefited most by burned clay, is consistent with the explanation of its mode of action which I have given in the preceding section. The action of different burned clays on different crops should nevertheless be carefully observed and recorded. For example,—

a With one clay against another similarly burned. Their respective physical characters and chemical composition ought at the same time to be noted.

b With a bad clay burned alone, and with an addition of lime.

c With both against a third portion to which a quantity of common salt has been added, and with a fourth which has been burned with an addition of both lime and salt.

§ 6.—*Suggestions for experiments with bituminous and other shales, burned and unburned.*

In connexion with surface clays, I would draw the attention of my readers to bituminous and sulphury shales, which are not unfrequently used with advantage in practical agriculture. A shale is a more or less indurated clay, which splits into thin shivery layers, and is called bituminous or sulphury according as it yields the one or the other on the application of heat. The bitumen is derived chiefly from vegetable matter, and the sulphur from iron pyrites with which the clay is impregnated. Both in the burned and unburned states, such shales have been applied to the land.

1°. *Unburned shale.*—Common coal shale, neither sensibly bituminous nor sulphury in a marked degree, has been used with advantage in improving and consolidating loose sands in the neighbourhood of coal mines from which the shale had been extracted. This is only a variety of claying or gaulting, and the mode in which it produces improvement is readily understood.

Subordinate to the Oxford clay, beds of bituminous shale occur in some localities which are found to benefit ordinary land. In the *Journal of the Royal Agricultural Society of England,** Mr Gowen has published the analysis of a shale of this kind which contained about 20 per cent of combustible matter, nearly as much carbonate of lime, and probably some sulphur, which is not stated. It occurs near Chippenham in Wilts, crumbles by the action of the frost, and forms a valuable top-dressing for grass land. Our coal shales rarely contain so much lime as this of Mr Gowen's, which is subordinate to the calcareous Oxford clay. Whatever might be the effect of its other ingredients, it contained lime enough to act as a marl, and might on this account alone be beneficial. Any other shales, however, which are crumbled by a winter's frost, may be tried on light and gravelly soils with the prospect of benefit.

2°. *Burned shales.*—Sulphury shales, wherever they occur, may be burned, as we burn clay, either alone, or, when they

* IV. p. 277.

are not naturally calcareous, with a small admixture of lime. As a top-dressing to grass land, as an application to soils in arable culture, and as an admixture for fermenting manures, such burned sulphury shales (smother burned) may be tried with advantage.

In some parts of Flanders, the burning of such shales for agricultural purposes, and even for sale to the farmers, is said to be extensively practised.

I would recommend, therefore, that wherever such sulphury shales occur, they should be tried—

a In the unburned state, when they are found to crumble by the action of the frost—alone or made into composts.

b In the burned state; first, burned without admixture; and, second, burned with a small admixture of lime, chalk, marl, shell sand, or other calcareous matter. During the burning this lime will arrest, and will form gypsum with, a portion of the sulphur, which would otherwise burn away and be lost.

c As a top-dressing for grass land, for young corn, clover, pulse, and corn crops, as an application to the land in preparing it for corn and beans, and in gardens as a manure for cabbage and similar leaf crops, and for destroying insects.

d As a mixture with night soil, and other strong smelling and fermenting manures. The sulphuric acid and iron the burned shale contains will cause it to act both as a fixer of ammonia, and as a deodoriser or remover of smells.

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